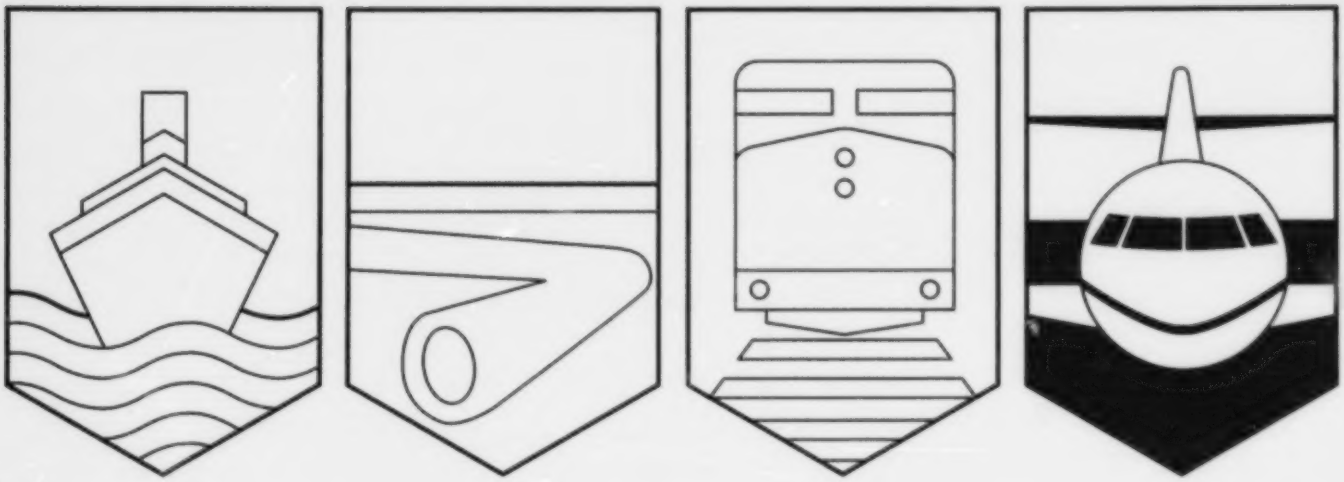
Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada



# AVIATION OCCURRENCE REPORT

## BRADLEY AIR SERVICES LTD.
## BRITISH AEROSPACE HS 748-2B C-GFFA
## CHENEY, ONTARIO
## 15 SEPTEMBER 1988

## REPORT NUMBER 88H0011

Canada

92-00632/

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

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## SYNOPSIS

The aircraft was in cruise flight at 3,000 feet in visual flight conditions while on an instrument flight rules flight to Ottawa International Airport from Montreal/Dorval Airport. Coincident with a remark by the captain pointing out a ground feature, the aircraft commenced a full aileron deflection roll to the left; the aircraft rolled 465 degrees and descended to impact with a final speed of approximately 290 knots. In the last stages of the accident manoeuvre, a maximum vertical acceleration of approximately 4.7 g was recorded. Both crew members on board were killed, and the aircraft was destroyed.

The Transportation Safety Board of Canada determined that the aileron control system was asymmetrically rigged, making it susceptible to aerodynamic overbalance. The operator did not conduct the required post-maintenance flight tests of the aileron control response. When the ailerons were held at full deflection by aerodynamic forces, following a large control-wheel input by the pilot, the subsequent control reaction by the pilot was inappropriate.

Contributing to the accident were the design of the aileron system; ambiguous and incomplete maintenance instructions; a lack of published information for flight crew concerning aileron system performance and possible emergencies; and the presence of factors which may have led to the development of flight crew fatigue.

18 June 1991

Ce rapport est également disponible en français.

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## 1.0 FACTUAL INFORMATION

### 1.1 History of the Flight

The aircraft, an HS 748-2B, C-GFFA, owned and operated by Bradley Air Services Limited, was being used for cargo flights from Montreal/Dorval Airport to Dayton, Ohio and back to Dorval. The positioning flight from Ottawa International Airport, departed from Ottawa at 1918 eastern daylight time (EDT)*, 14 September 1988. The aircraft landed at Dorval at 1950 EDT. During the period that the aircraft was on the ground at Dorval, it was not refuelled, and it was loaded with about 4,000 pounds** of cargo. The aircraft departed Dorval at 2047 EDT for Dayton and arrived at 2359 EDT.

At Dayton, the off-loading of the cargo began approximately 15 minutes after arrival and was completed in less than one hour. The aircraft was refuelled at 0215 EDT. Loading of the 10,200 pounds of cargo commenced at 0320 EDT and was completed at 0453 EDT.

The flight departed Dayton for Montreal at 0514 EDT and arrived at Montreal/Dorval Airport at 0825 EDT. All the cargo was unloaded in Montreal; the aircraft was not refuelled. The aircraft departed at 0958 EDT for Ottawa on an instrument flight rules (IFR)*** flight plan.

After departure from Montreal, the aircraft levelled at the flight planned altitude of 4,000 feet above sea level (asl) en route to Ottawa via the Victor 316 airway. The flight was cleared direct to the Ottawa beacon by Ottawa Terminal at 1014 EDT and, three minutes later, the aircraft was cleared to descend to 3,000 feet asl. The descent clearance was acknowledged by the crew, and the aircraft descended to the cleared altitude, levelling at 1018 EDT.

At about 1019 EDT, while the aircraft was in level cruise flight at approximately 200 knots indicated airspeed (KIAS), the flight data recorder (FDR) recorded a full-up deflection of the left aileron and a full-down deflection of the right aileron, and the

* All times are EDT (Coordinated Universal Time (UTC) minus four hours) unless otherwise stated.
** Units are consistent with official manuals, documents, reports, and instructions used by or issued to the crew.
*** See Glossary for all abbreviations and acronyms.

aircraft began a roll to the left at a high rate. The right aileron remained at the fully-deflected position for a period of three seconds, and then, over the next seven seconds, the deflection gradually decreased by about five degrees. During the same 10-second period, the left aileron remained nearly fully deflected for the first eight seconds, then the deflection decreased by about five degrees during the next two seconds. By this time, the aircraft had rolled through approximately 460 degrees, and the aircraft nose had dropped 20 to 30 degrees below the horizon. At this point, the ailerons suddenly returned to about the neutral position and remained there for the last three seconds of the flight. The aircraft bank angle remained at approximately 90 degrees of left bank with a maximum vertical g of 4.7 recorded. (See Appendix A)

A number of witnesses observed the aircraft during the accident sequence and saw the aircraft crash. Witnesses observed the aircraft in a roll as the aircraft was abeam the village of Hammond, about 1.2 nautical miles (nm) east of the accident site.

The aircraft struck the ground at an airspeed of approximately 290 KIAS after a heading change of about 75 degrees left of the cruise heading. At impact, the aircraft bank angle was nearly 90 degrees left and the pitch angle was 41 degrees down. The time from the initial aileron deflection to ground impact was approximately 18 seconds.

Both pilots were fatally injured in the crash. The accident occurred at 1019 EDT, during the hours of daylight, approximately 18 nm east of the Ottawa International Airport at lat 45°25'10"N, long 75°15'25"W, at an elevation of 253 feet asl.

## 1.2 Injuries to Persons

| | Crew | Passengers | Others | Total |
|---|---|---|---|---|
| Fatal | 2 | - | - | 2 |
| Serious | - | - | - | - |
| Minor/None | - | - | - | - |
| Total | 2 | - | - | 2 |

## 1.3 Damage to Aircraft

The aircraft was destroyed by the impact.

## 1.4 Other Damage

There was no other damage.

## 1.5 Personnel Information

| | Pilot-In-Command | Co-Pilot |
|---|---|---|
| Age | 37 | 25 |
| Pilot Licence | Airline Transport | Airline Transport |
| Medical Expiry Date | 01/06/89 | 01/06/89 |
| Total Flying Time | 5,500 hr | 1,750 hr |
| Total on Type | 1,700 hr | 200 hr |
| Total Last 90 Days | 272 hr | 185 hr |
| Total on Type Last 90 Days | 272 hr | 185 hr |
| Hours on Duty Prior to Occurrence | 16 hr | 16 hr |
| Hours off Duty Prior to Work Period | 7 hr | 7 hr |

### 1.5.1 The Captain

The captain obtained his private and commercial training between 1969 and 1974. In 1975, he received his multi-engine endorsement and, in 1977, he received an instrument rating.

The captain was initially hired by Bradley Air Services in 1981 as a first officer on the Cessna C550/500 and the DHC-6 (Twin Otter). He qualified as an HS 748 first officer in October 1985, upgraded to C550/500 captain status in 1987, and achieved HS 748 captain status in January 1988. The captain had type ratings for the HS 748, Cessna 550, and Grumman Mallard. His last instrument flight check was completed 04 January 1988; his last HS 748 pilot proficiency check (PPC) was completed 31 May 1988.

A review of company training records indicated that the captain was an average pilot who generally achieved satisfactory assessments. Aircraft knowledge was adequate; however, at times, instructors and flight test examiners noted a tendency to be slow in anticipating problems.

Recent check-rides had been fully satisfactory, and the captain was asked by the company to consider accepting the responsibility of a training/check-pilot. He declined, stating that he disliked the physical sensations of negative/positive g forces which are experienced during some training exercises.

Review of the captain's flying record showed no evidence of aircraft accidents or dangerous operation of aircraft. In general, the captain was characterized as a cautious, average pilot and a good, quiet, and reliable company employee. He was well liked within the company. There was no indication that the captain had ever received any aerobatic training or had been exposed to aerobatic flight. The captain was known to be a cautious individual who respected rules and regulations. He was not known to be overly aggressive on the controls or to stunt and show off. The captain was required to wear glasses while flying.

### 1.5.2 The First Officer

The first officer obtained his Private Pilot Licence in 1982. In May 1985, he obtained his Diploma of Aviation and Flight Technology from Seneca College of Applied Arts and Technology, Toronto. Between May 1985 and January 1986, he was employed as a charter pilot and instructor in the Toronto area.

The first officer was first employed by Bradley Air Services in January 1986; his initial position was as a DHC-6 first officer in the Arctic. He was first qualified on the HS 748 in June 1987. A review of company training records showed a high standard, which was consistently maintained. All flight checks were completed with generally above average performance. Comments by flight test examiners and company pilots indicated that the first officer handled the HS 748 well, was making very good progress, and was generally regarded as hard working and conscientious. The company had planned that, during the winter of 1988/89, the first officer would be trained for upgrading to HS 748 captain status.

Examination of company records and Transport Canada licensing files indicated no record of aircraft accidents, licence suspension, regulatory infractions, or disciplinary action. There was no record of the first officer's ever having operated any aircraft in a dangerous or unprofessional manner. There were no records of his ever having received any aerobatic training or instruction. The first officer was type-rated for the HS 748; his last pilot proficiency and instrument checks were completed on 31 May 1988.

The first officer was considered to be a happy, active, outgoing person who got on well with other people and was well liked.

### 1.5.3 Crew Schedule

The accident flight was the third successive daily flight to Dayton and return via Montreal/Dorval, for both pilots flying together as a crew. The previous two flights had each required flight duty times of approximately 16 hours. At the time of the accident, the crew had been on duty slightly more than 16 hours.

The crew's schedule for the three series of trips is shown below:

| Place | Time, EDT | Ground Time (hr:min) | Flight Time (hr:min) |
|---|---|---|---|
| *Dep Ottawa | 1912 (12)*** | | |
| **Arr Montreal | 1950 | | 0:38 |
| Dep Montreal | 2045 | 0:55 | |
| Arr Dayton | 2400 | | 3:15 |
| Dep Dayton | 0412 (13) | 4:12 | |
| Arr Montreal | 0805 | | 3:53 |
| Dep Montreal | 0943 | 1:38 | |
| Arr Ottawa | 1013 | | 0:30 |
| Dep Ottawa | 1918 | 9:05 | |
| Arr Montreal | 2007 | | 0:49 |
| Dep Montreal | 2043 | 0:36 | |
| Arr Dayton | 2400 | | 3:17 |
| Dep Dayton | 0502 (14) | 5:02 | |
| Arr Montreal | 0800 | | 2:58 |
| Dep Montreal | 0942 | 1:42 | |
| Arr Ottawa | 1020 | | 0:38 |
| Dep Ottawa | 1911 | 8:51 | |
| Arr Montreal | 1950 | | 0:39 |
| Dep Montreal | 2045 | 0:55 | |
| Arr Dayton | 0001 (15) | | 3:16 |
| Dep Dayton | 0505 | 5:04 | |
| Arr Montreal | 0825 | | 3:20 |
| Dep Montreal | 0955 | 1:30 | |
| Accident | 1019 | | 0:24 |

* Departure
** Arrival
*** Date in brackets, September 1988

On each flight to Dayton, the crew took sleeping bags and mattresses with them. It was normal for the crews to try to sleep in the aircraft cabin while on the ground at Dayton, but it is not known if the pilots were able to sleep during the first two duty days. On each of the preceding days, the time for the ground

stop between the end of the unloading and the commencement of refuelling was approximately one hour and 30 minutes; the interval from the end of the refuelling and the start of loading was about one hour.

On the last flight to Dayton, off-loading of the cargo started at 0015 (15 September) and finished at 0100 EDT. Refuelling started at 0201 and ended at 0215 EDT. The pilots were awake and active in and around the aircraft between the end of the off-loading and the refuelling. At 0320 EDT, the ground handlers arrived to load the aircraft and woke the pilots.

Between the flights of 13 and 14 September, the captain slept about 3.5 hours each day. At no time did the captain indicate that he was fatigued; however, he was described as a person who rarely complained about anything.

The first officer slept approximately five hours during the day on 13 September and about 4.5 hours on 14 September. He commented on 14 September, prior to reporting for duty, that he found the series of trips to Dayton tiring.

## 1.6 Aircraft Information

### 1.6.1 Description

| | |
|---|---|
| Manufacturer | British Aerospace |
| Type | HS 748-2B |
| Year of Manufacture | 1981 |
| Serial Number | 1789 |
| Certificate of Airworthiness | Valid |
| Total Airframe Time | 10,004 hr |
| Cycles | 14,733 |
| Engine Type (2) | Rolls Royce Dart 535-2 |
| Propeller Type (2) | Dowty Rotol CR 212/4-30-4/22 |
| Maximum Allowable Take-off Weight | 46,500 lb |
| Recommended Fuel Type(s) | Jet A and/or other aviation wide-cut fuels |

The aircraft was certified and equipped in accordance with existing regulations and approved procedures.

The accident aircraft's production flight test was carried out on 21 September 1981. As a result of the flight test, an adjustment was made to the flying controls. The "left aileron trim control rods were screwed in 1 and 1/2 turns."

When questioned about the flying qualities of C-GFFA, most pilots did not indicate that there were any problems with the aircraft. Some pilots indicated that C-GFFA was the best aircraft in the fleet in terms of flight control forces. One pilot stated that the aircraft flew with the control wheel "somewhat to the right" when flying straight and level.

The weight and centre of gravity of the aircraft were within the prescribed limits at the time of the accident.

### 1.6.2 Flight Controls

The HS 748 is equipped with conventional dual controls and adjustable trim tabs. The primary control surfaces are actuated by the use of cable and tie rod circuits together with push rods. This provides a direct mechanical connection between the cockpit and the control surface. In case of a primary control failure, adequate control is available on the trim tabs. All flight controls are manually operated with no hydraulic system involvement.

The elevator trim tabs are controllable balance tabs. They are controlled by individual screwjacks which are adjusted via a cable system from the cockpit.

The rudder is a single horn balanced control attached to the vertical fin rear spar. The rudder incorporates an adjustable trim tab and a movable spring tab. The spring tab compensates for changing aerodynamic forces at different airspeeds.

Provision has been made for an internal mechanical control lock (gust lock). The control locks are mechanically locked in a neutral position by sliding a locking lever with a roller into a cam slot in each of the tension regulators, thereby preventing the control surfaces from moving. The control lock system is cable actuated and controlled from the cockpit. Provision has been made to make it impossible to engage the control locks with the propeller in a power setting required for flight.

### 1.6.3 Aileron System

The aileron system on the HS 748 is a classic manually operated reversible design. A control wheel moves the ailerons by direct connection of cables and bell-cranks; the pilot feels a proportionate amount of the airloads the ailerons are experiencing. To keep the pilot effort reasonable, each aileron has a lagging geared tab that is actuated by aileron movement. On

aileron movement, each lagging tab provides an aerodynamic force that helps to move its aileron in the direction of the pilot's control-wheel input. This tab is adjustable; "screwing in" the adjustment rod shortens it, which in turn causes a greater tab to aileron angle, decreasing control forces felt by the pilot.

The aileron system is designed with the aileron hinges offset 22.5 per cent of the aileron chord from the aileron leading edge, to provide overhang balance. Additional aerodynamic balance is provided by an outboard horn balance on each aileron. The right aileron's geared tab can be biased to provide aileron trim by a screwjack turned by a roller-chain driven sprocket. The ends of the roller chain are connected by cables to the aileron trim wheel in the cockpit. The aileron trim system, like the aileron system itself, is completely manual in operation. The aileron system is shown in Figure 1.1.

There are two aileron wing cable loops, one for each aileron with four control cables per aileron wing loop. Considering the right aileron wing loop, the upper or aileron pull-down cable located along the aft spar of the wing is made up of two cables joined by a turnbuckle. Each cable has unique terminations so that its ends fit and connect an inboard quadrant to an outboard quadrant, adjacent to the inboard end of the aileron. The lower or pull-up cable is also composed of two cables joined by a turnbuckle. Its ends connect the two quadrants previously described. This cable parallels the pull-down cable, running about two inches below it along the aft spar. The left wing loop is similarly configured, but has cables of different length than those of the right wing loop, with the objective of making erroneous installation impossible.

The aileron system fuselage loop joins the quadrant assembly located under the cockpit floor to a tie-rod assembly which in turn attaches to a tension regulator mounted in a bracket attached to the aft face of the rear spar at the port wing root. The cable tension regulator maintains tension of the fuselage loop only. This cable tension regulator is designed to maintain the cable tension of the fuselage loop within reasonable limits under varying temperatures and flight conditions. The rest of the aileron control circuit, which consists of the crew compartment aileron balance loop and the right and left aileron wing loop circuits, must be ground adjusted by maintenance personnel using a hand-held cable tensiometer for tension measurement and accounting for temperature.

Each aileron is attached to a quadrant assembly (located at the outboard end of its respective wing loop) by means of two push-pull rods operating through a bell-crank. Aileron stops located on each wing quadrant limit aileron travel to 18.5 degrees (+1,-0). The final rigging adjustment of the aileron is made by adjusting the rod end of the push-pull rod connected to the aileron attachment arm.

HS 748 aircraft do not have provisions for, or make use of, rigging pins for control surface rigging. Proper aileron rigging is established by aileron angle measurements and painted alignment marks on the control cable quadrants and bell-cranks.

The aileron trim tab cable system has separate cables and a separate tension regulator, making it completely independent of the aileron cable system. Its tension regulator is mounted on the aft face of the right wing's rear spar.

The ailerons each have an outboard horn balance. The ailerons are designed as an overhang balance system with additional aerodynamic balance provided by the horns. An elliptical nose and offset hinges provide further tailoring of the aerodynamic hinge-moments occurring on control displacement.

The net effect of these provisions is a non-linear hinge-moment characteristic as depicted in Figure 1.2; this hinge-moment curve is derived from ATP flight data, corrected theoretically for the different tab gearing. At zero deflection, an isolated aileron has a down-floating tendency, but, as a pair, the ailerons counterbalance each other. The aileron system has stable hinge-moment characteristics up to about half travel. However, at larger angles, the aerodynamic balances protrude sufficiently into the air stream to cause the hinge-moment characteristics to adopt an unstable gradient. This behaviour occurs first on the up-going aileron. Protection from aerodynamic overbalance or "lock" is provided by the then increasing hinge moment on the down-going aileron. Thereafter, some lightening of wheel forces occurs. Correct rigging is required for the designed protection from aileron aerodynamic overbalance.

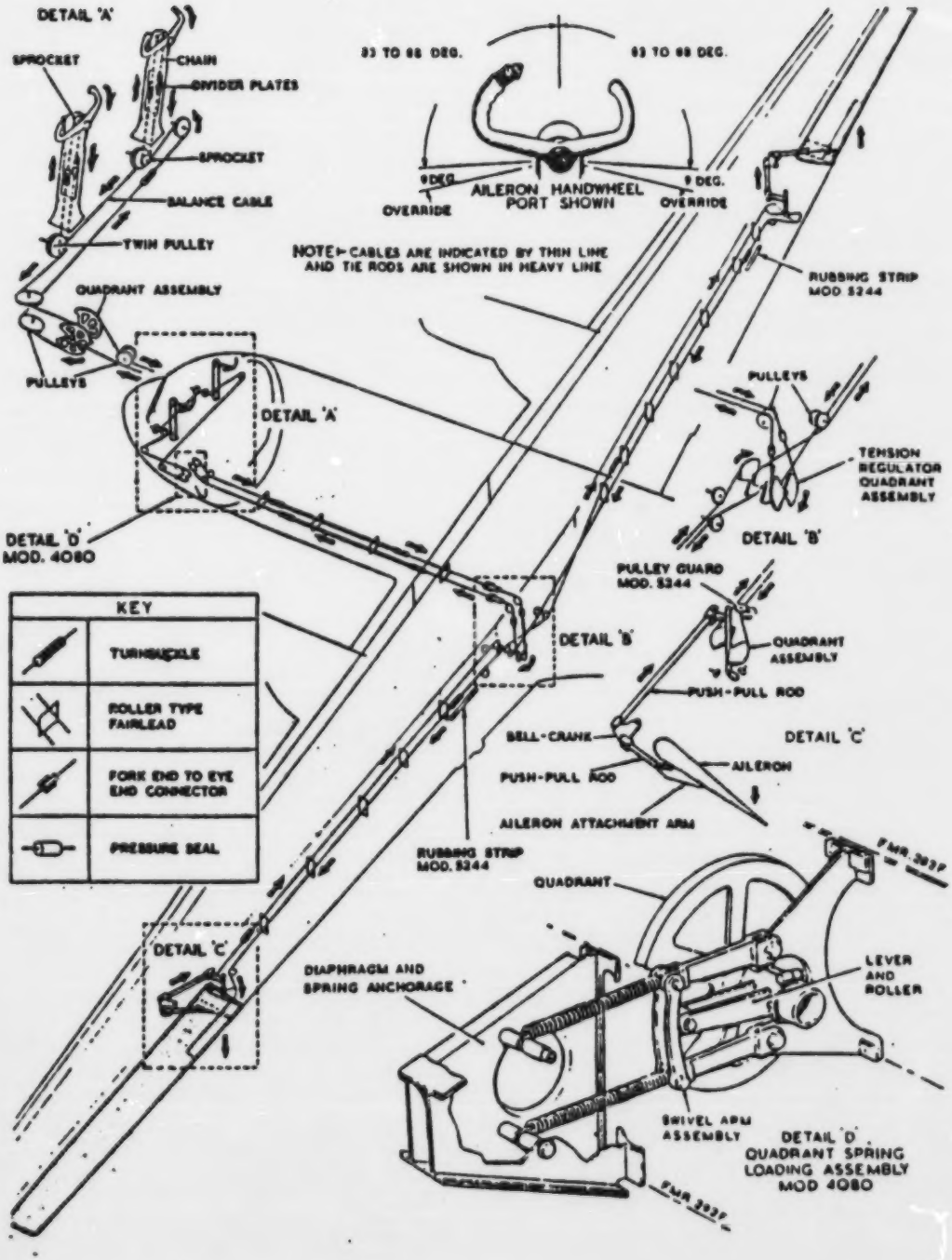


**Figure 1.1 Aileron Control System**

At large deflection angles (greater than 20 degrees above the chord line), the up-going aileron would be driven upwards by aerodynamic forces were it not restrained by its cable connection to the down-going aileron. At this point, the force that the pilot must overcome in moving the ailerons is the total of system friction and the resistance of the down-going aileron less the force provided by the up-going aileron's tendency to go up.

The net force balance is a function of the neutral position of the ailerons. If they are both rigged up from the wing chord line, aileron control wheel forces will lighten. With normal rigging of the aileron system, that is, with both ailerons rigged trailing edge 1.5 degrees up from the wing chord line, the aileron wheel force falls steeply for aileron deflections of more than 12 degrees from neutral. A centring spring system (Modification 4080), which comes into play at about 14 degrees mean aileron angle, progressively adds wheel return force, reaching approximately 17 pounds at the normal maximum control-wheel angle of 88 degrees, to reduce the lightening of the wheel forces at large mean aileron angles.

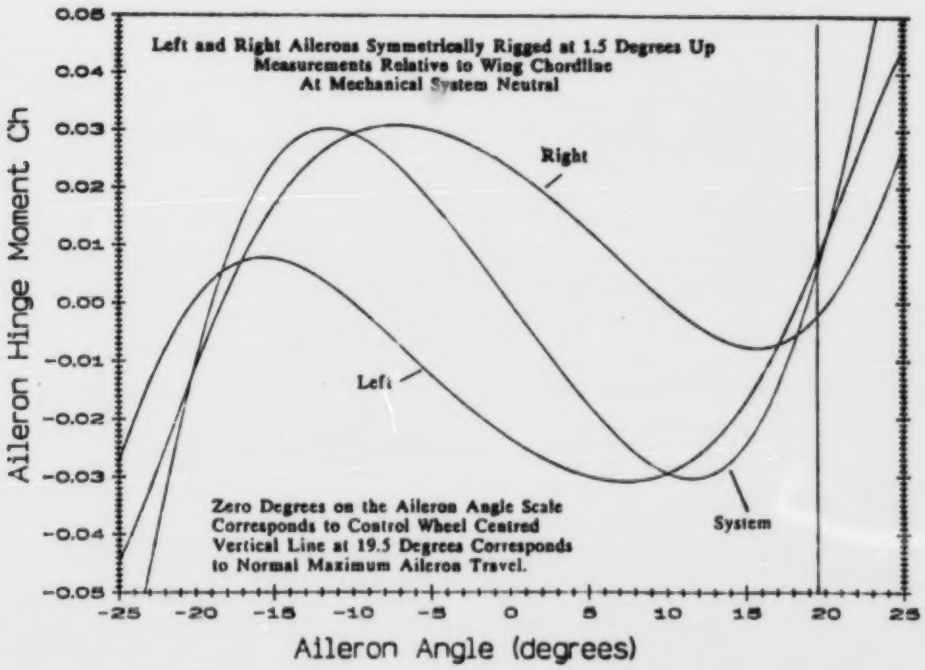


**Figure 1.2 Aileron Hinge-Moment Characteristics (Rigged Up 1.5 Degrees from Chord Line)**

The manufacturer estimates that the HS 748 roll rate, with fully deflected, normally rigged ailerons, would be about 36 degrees per second at 200 KIAS.

**1.6.4 Fuel System**

In the HS 748-2B, fuel is stored in an integral tank in each wing. Each tank is divided into two compartments which are designated main cell and tip cell. The main cell and the tip cell are separated by a barrier incorporating a weir stand-pipe. Fuel is gravity fed from each main cell to a corresponding collector tank, and each collector tank contains two fuel booster pumps which supply low pressure fuel to the engine fuel pumps. The fuel in each tip cell is retained until the main cell fuel level drops to approximately 120 pounds, at which point, the fuel in the tip cell is automatically fed into the collector tank. Fuel is kept in the tip cells as long as possible because of wing bending moment considerations. Spillage of fuel from the tip cell to the main cell through the stand-pipe caused by changes in aircraft attitude is compensated for by a tip cell top-up system which feeds excess fuel from one of the boost pumps to the tip cell.

When the level in either tip cell drops to approximately 440 pounds or less, a float switch is activated. This switch illuminates a corresponding wing tip low-fuel-level warning light on the centre instrument panel. During the normal sequence of fuel use, each of these lights will illuminate when the total fuel in each wing decreases to approximately 660 pounds. If one or both of these lights illuminate at any other time, then this indicates that the fuel in the tip cell(s) is not being maintained. In the event that this happens, then the following Flight Manual limitations apply:

> If one fuel tip low-level indicator is illuminated, the maximum permissible lateral unbalance is 250 pounds.
>
> If both fuel tip low-level indicators are illuminated, the maximum permissible lateral unbalance is 500 pounds.
>
> If either fuel tip low-level indicator illuminates in flight, the maximum operating speed must be reduced to 200 knots IAS and the above fuel limitations must be observed using fuel cross-feed if necessary before landing.

### 1.6.5 Autopilot

The SPZ-500 flight control system consists of a two-axis autopilot (pitch and roll with automatic pitch trim), and an independent yaw damper. When the autopilot is initially selected, it is in a pitch attitude and heading hold mode. Pitch is controlled by the PITCH control on the autopilot controller. Heading is controlled by the TURN control on the autopilot controller.

The manufacturer estimates that an aileron hardover malfunction produces only six degrees of aileron travel which would produce about 11 degrees per second roll rate. The maximum wheel force the autopilot can generate is about 30 pounds. The pitch, roll, and yaw channels use electronic servo torque limiting circuits with independent monitors. If a torque limit monitor operates, the autopilot disengages. Roll attitude is limited to 35 degrees of bank, and roll rate is limited to five degrees per second if loss of the heading signal results in a roll channel runaway.

### 1.6.6 Aircraft Warning Systems

The aircraft was equipped with a Ground Proximity Warning System (GPWS). This system is designed to provide visual and aural warnings of hazardous approach to terrain. Mode 2 alerts for "excessive closure rate to terrain." Mode 4(a) warns of "flight into terrain with less than 500 feet clearance and landing gear up." In the event of a warning detected in Modes 1 to 4 inclusive, an audio signal will generate the repeated command "Whoop Pull Up" and two Pull Up/GPWS Test lights will be visible to the crew. The activation of the GPWS is recorded as a discrete parameter of the FDR.

An Altitude Alert System was installed on the aircraft. This system provides visual and audio warnings of deviations from a selected altitude reference. If the aircraft deviates more than 250 feet from the selected altitude, an alert light will illuminate and a momentary (one-second) audio tone will sound in each pilot's head-set.

### 1.6.7 Maintenance History

The operator acquired the aircraft in the United States (U.S.) five months prior to the accident. Prior to its purchase, the aircraft had been in storage for about two years. Before importation into Canada, considerable maintenance was carried out on the aircraft by a U.S. contractor, in Phoenix, Arizona, on

behalf of the operator. Representatives of the operator were present during the maintenance. The one-, two-, three-, and six-year calendar inspections were accomplished. This maintenance included replacement of the gust-lock cables (life-limited item) and removal, repair as necessary, repainting, then reinstallation of all the primary flight control surfaces; also included were repairs to the right aileron. There is no indication that control cable tensions were checked during the inspections.

Prior to removal of the ailerons from the aircraft, measurements were taken at their trailing edges relative to the wing trailing edge. The "left aileron" trailing edge was "28/64 inches" (0.44) above the wing trailing edge; the "right aileron" measurement was "28/32 inches" (0.875). A displacement of 0.19 inches equals 0.75 degrees of aileron rigging.

The left aileron from another HS 748-2B (C-GBFA, which was purchased at the same time) was installed on C-GFFA as a result of a mix-up, when all ailerons for both aircraft were removed and stored in the same area. When the error was discovered, the operator decided to have maintenance entries raised, indicating that the left ailerons were changed on both aircraft. When the accident aircraft left the U.S. contractor's facility, its left aileron was the original factory-installed left aileron from C-GBFA.

Pilots employed by the operator test flew the aircraft following the maintenance in the U.S. A test card was not used, and no attempt was made to evaluate aileron rigging by using procedures contained in the HS 748 Maintenance Manual.

During the period that the company operated the aircraft, the following maintenance had been conducted on the flight control systems:

> The flight controls were "checked for general condition and security of attachment" on 10 August, because of an entered journey log discrepancy "Mild buffeting 135 to 155 kts on climb from YOW."
>
> Both elevators were removed 17 August to comply with "P10Z11 item #55-50-2 inspection requirements." All the elevator hinges were checked for condition and were lubricated; the elevators were then reinstalled.

On 18 August, the gust-lock cables were re-tensioned because it was possible to "turn the ailerons to the right" with the gust lock engaged.

A new aileron "attachment arm" was installed on the right aileron 30 August, as a result of a discrepancy "Capt control yoke turned to right slightly in level flight." The bracket (attachment arm) had suffered compression damage. Some thought that the damage was caused by wind or jet blast coming toward the aircraft from behind, but this could not be confirmed. No test flight was carried out following the aileron repair, nor was an inspection for other damage to the aileron system carried out.

On 03 September, an entry "elevator trim wheel binds occasionally" was rectified by "elevator trim checked satisfactory."

A journey log entry made on 04 September indicated that the starboard tip low-fuel-level light was flashing continuously with 2,000 pounds of fuel in the tanks. This defect was deferred with a caution to "observe procedures as per A.F.M."

Other deferred maintenance items at the time of the accident included:

"All flight control drag reduction seals to be replaced" (May 1988).

"Gust lock indicator system cables to be checked for proper tension as per MM 27-70-0 para 9. The functional check was carried out as per P10Z13 check but no tensiometer to check cables" (06 September 1988).

Control cable tension is checked during a 4,000-hour inspection. This inspection period had not yet been reached while the aircraft was in the possession of the operator.

## 1.7 Meteorological Information

On 15 September 1988, the Ottawa-Montreal area was under the influence of a moderate northwesterly flow with some low-level moisture. A combination of the instability of the air and daytime heating produced scattered cumulus-type clouds with bases 2,500 to 3,000 feet above ground level (agl). Observations taken in the area and satellite photos indicate that there were no towering cumulus clouds in the area at the time of

the accident. According to Environment Canada, light mechanical turbulence could have been experienced between 2,000 and 4,500 feet. The area forecast, valid for the time of the accident, predicted occasional moderate turbulence below 5,000 feet asl because of gusty surface winds.

The Ottawa 1400 UTC (1000 EDT) weather report was as follows:

> Scattered (3/10) cumulus cloud based at 2,400 feet above ground level (agl), 25 miles visibility, temperature nine degrees Celsius, dew point three degrees Celsius, wind 340 degrees true at 12 knots, altimeter setting 30.30 inches.

A special weather report for Ottawa taken at 1434 UTC (about 15 minutes after the accident) was as follows:

> Scattered cloud at 2,800 feet agl, visibility 25 miles, and wind from 300 degrees true at 11 knots gusting to 16.

A comment by the crew of the accident flight, recorded on the cockpit voice recorder (CVR), indicated that they were flying near or in cloud when cruising at 4,000 feet. There was a comment indicating that hand-flying was difficult, but there was no specific reference indicating that turbulence was present.

A Transport Canada helicopter pilot flying over the accident site at 1,000 feet asl, approximately one hour after the accident, did not report any turbulence. A Transport Canada Dash 8 crew was flying up to 3,500 feet asl in the Ottawa Terminal Area at the time of the accident and flew over the accident site at 1,000 feet asl approximately 10 minutes after the crash. The Dash 8 crew did not experience any turbulence.

## 1.8 Aids to Navigation

During the en route portion of the trip, the aircraft was navigating via the Victor 316 airway using the Montreal very high frequency omni-directional range (VOR) and the Ottawa VOR. Both VOR facilities were indicating serviceable for the duration of the trip. Once the aircraft was under the control of Ottawa Terminal and was cleared to the Ottawa (OW) beacon, the crew tuned in the OW beacon and the instrument landing system (ILS) frequency for runway 32 (the active runway) and selected the distance measuring equipment (DME) to 108.8 megahertz (MHz) for the DME facility from the Tactical Air Navigation Equipment (TACAN)

located at Ottawa Airport. All of these navigation aids were functioning normally at the time of the accident.

## 1.9 Communications

Once airborne, the crew contacted Montreal Departure on a frequency of 124.65 MHz. Company dispatch at Ottawa was contacted shortly after take-off to pass load, fuel, and departure time information. At 1009 EDT, the crew switched to Montreal Centre on 134.4 MHz and then, at 1013 EDT, to Ottawa Terminal on 135.15 MHz. At 1014 EDT, the Ottawa Terminal controller cleared the aircraft to the OW beacon and then, at 1017 EDT, cleared the aircraft to descend to 3,000 feet asl. This clearance to descend was acknowledged by the crew and was the last radio transmission made by the crew.

## 1.10 Aerodrome Information

Not applicable.

## 1.11 Flight Recorders

The aircraft was equipped with a digital FDR with capabilities that exceeded current Transport Canada requirements for the HS 748. A CVR was also installed. Both the FDR and the CVR were recovered in the wreckage. Only the section of the FDR containing the recording tape and recording heads was recovered; the electronics section had separated from the FDR during the crash. The CVR was recovered intact, although the case had been badly dented and crushed by the impact forces.

### 1.11.1 Flight Data Recorder

#### 1.11.1.1 Description

The FDR was a Plessy PV 1584 D digital recorder that recorded 21 parameters. Calibration data were available for all parameters except for fine altitude, which was determined to be unserviceable.

#### 1.11.1.2 Aileron Calibration

Both the left and right aileron movements were recorded. However, the operator was not aware that the left aileron position was a recorded parameter; consequently, calibration data for that parameter had to be derived from the recorded counts from the aileron

calibration tests (full wheel deflection in each direction). A copy of the FDR tape from the calibration tests at Phoenix was provided to Transport Canada; the tape was then sent to National Aeronautical Establishment, Flight Recorder Playback Centre (FRPC). The tape was obtained from the FRPC, and the counts from the hand recorded data for the right aileron were shown to compare closely with that recorded on the FDR tape. The tape recorded counts for the left aileron were extracted from same FDR aileron test points used to calibrate the right aileron.

Aileron calibration data consisted only of full control-wheel deflection points (left and right) and the gust lock neutral position. It was assumed that full left-wheel to full right-wheel deflection, during ground tests, produced a total of 37 degrees of aileron travel. A third order polynomial fit, through the three known left aileron points was used to yield aileron movement values from recorded counts. Transducer accuracy was estimated to be better than 0.5 degrees.

The design of the ailerons and the transducer location in the system require that the aileron position parameters be re-calibrated whenever rigging alters the aileron neutral point, relative to the wing chord. Deflection is relative to the rigged neutral. Determining angular position relative to the chord line requires accurate neutral-rigged position information; this information was not known. To determine aileron position, it was assumed that both ailerons were at the same deflection angle, the approximate normal float-down position of minus 0.4 degrees, relative to the chord line, during cruise (otherwise the aircraft would roll). Accordingly, the left aileron gust-lock neutral-point rigging was determined to be about 3.0 degrees up from the chord line. The right aileron remained close to the assumed 0.4 down position while in cruise.

Below is a summary of FDR counts and aileron position (using the above assumptions) versus wheel position for each aileron as derived from calibration tests carried out at Phoenix:

Right Aileron

| | | | |
|---|---|---|---|
| Right wheel (full) | = 606 counts | = -18.1 deg | (up) |
| Gust Lock (neutral) | = 497 counts | = +0.4 deg | (down) |
| Left Wheel (full) | = 370 counts | = +18.9 deg | (down) |

Left Aileron

Right wheel (full) = 11 counts = -15.5 deg (down)
Gust lock (neutral) = 155 counts = +3.0 deg (up)
Left wheel (full) = 262 counts = +21.5 deg (up)

Float down (gust-locked to cruise) = 23 counts = 3.5 deg

The difference of counts from the left to right full wheel deflections divided by the aileron travel yields an approximate value of 6.5 counts per degree of aileron travel.

### 1.11.1.3 Recorded Data

The air traffic control directed descent from 4,000 to 3,000 feet was recorded. The maximum speed reached during this descent was approximately 230 KIAS. The recorded level-off altitude was about 2,950 feet. The recorded airspeed, immediately prior to the flight upset leading to the accident, was approximately 200 KIAS. The recorded heading was approximately 270 degrees magnetic.

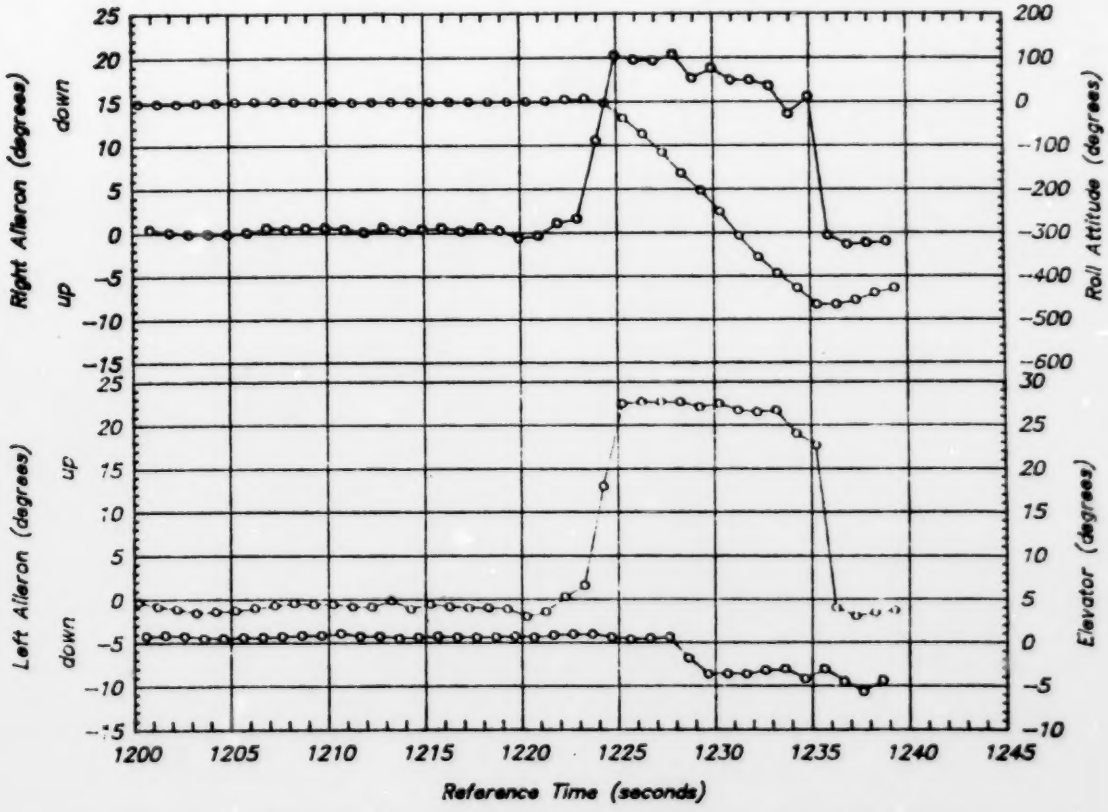


**Figure 1.3 FDR Recorded Aileron Deflections and Roll**

The data (Figure 1.3) indicates that the flight upset took a total of 18 seconds from the commencement of the aileron deflections until ground impact. The sequence started with a very slight roll to the right which appears to be arrested quickly with a small amount of aileron application. The aileron deflections were applied at a slow rate from 1221 reference time (RT, in seconds, zero RT selected when the aircraft was on the ground in Montreal). At 1223.5 RT, the rate of aileron deflection and the roll rate to the left increased sharply; the left aileron was deflected upward and the right aileron downward. At 1225 RT, the ailerons reached deflected values of nearly 23 degrees up for the left aileron and 21 degrees down for the right aileron, relative to the chord line. Both ailerons remained deflected until 1235 RT. At that time, the aileron deflection changed abruptly toward zero, remaining slightly past the previously recorded in-flight neutral point, from 1237 RT to impact (1239.4 RT). During this 18-second period, the aircraft rolled to the left through a total of about 465 degrees. In the last two seconds of flight, the left rolling had been stopped and a slight rolling to the right had commenced, with the aircraft having a bank angle greater than 90 degrees.

The ailerons went to maximum deflection in approximately 2.5 seconds. The value for the right aileron deflection during the accident manoeuvre was 2.3 degrees greater than the full wheel deflection aileron positions determined during FDR ground calibration tests conducted by the operator in Phoenix (355 counts or 15 extra counts divided by 6.5). The left aileron deflected approximately 1.2 degrees greater than the full wheel calibration value (270 counts or 8 extra counts).

The aircraft rolled to the left (the direction appropriate for the deflection) at a maximum roll rate of about 46 degrees per second (278 degrees of roll in six seconds, from 1226 RT to 1232 RT). During this period, the ailerons remained at or near the fully deflected position. The left aileron deflection varied slightly, reducing by a maximum of about 1.0 degrees at 1233 RT; a gradual reduction was then noted, yielding a deflection value of about 18 degrees at 1235 RT. The right aileron deflection reduced momentarily to about 19 degrees at 1230 RT and then commenced a steady slow reduction to about 14 degrees at 1234 RT. The recorded right aileron deflection returned to about 15 degrees at 1235 RT.

As the roll continued towards the 180-degree or inverted position, the nose of the aircraft began to drop below the horizon so that, at the inverted position, the pitch attitude was 20 degrees nose down. At this point, the airspeed began to increase and the altitude began to decrease.

When the aircraft was nearly inverted, with a bank angle of approximately 160 degrees (1228 RT), the elevator deflected three to four degrees up (relative to the aircraft axes). The aircraft vertical g loading increased to 2.5 positive, and the nose continued to drop to a pitch attitude of 35 degrees nose down. By the time the aircraft was wings-level (upright) again, the airspeed had increased through 240 KIAS and the altitude was passing 2,000 feet asl.

Seven seconds elapsed from passing through wings-level (after 360 degrees of roll) to ground impact (1232 to 1239 RT). Both ailerons abruptly returned to the previously noted in-flight neutral position at 1236 RT. The ailerons then went to slightly past the previously noted in-flight neutral position. This resulted in the roll stopping with the roll attitude of the aircraft at about 100 degrees of left bank and the commencement of rolling motion in the opposite direction.

The vertical g (referenced to the aircraft axes) increased steadily during the upset, commencing at 1228.5 RT. At this time, the aircraft roll attitude was approximately 160 degrees. The g values remained above 2 g and remained near 3 g for about three seconds (1232.5 to 1236 RT). From 1236.5 RT to 1238 RT, vertical g increased to a peak of 4.7 g. A corresponding increase of elevator angle (to about 5.5 degrees) was noted at the same time as the maximum value of vertical g.

At impact, the recorded pitch attitude was 40 degrees nose down, and the airspeed had increased to about 290 knots.

The flaps did not move from the full-up position during the flight upset. Rudder movement of about one degree from the flight neutral position was recorded. There was no observable change in elevator trim recorded during the flight upset.

There was no indication of engine power loss (rpm or torque). Engine power was nearly symmetrical, and normal expected values were recorded during all phases of the flight.

There was no discrete indication of GPWS activation recorded on the FDR during the flight upset.

As previously indicated in section 1.11.1.2, it was noted that there was about 3.5 degrees of downward movement (float down) in the left aileron neutral position from the on-ground, no airload condition (gust-locked) to the flight loaded condition at 200 KIAS. No observable change was recorded in the neutral position of the right aileron when it was subjected to airloads (Figure 1.4). This float down phenomena was observed in all 25 hours of data on the accident FDR tape.

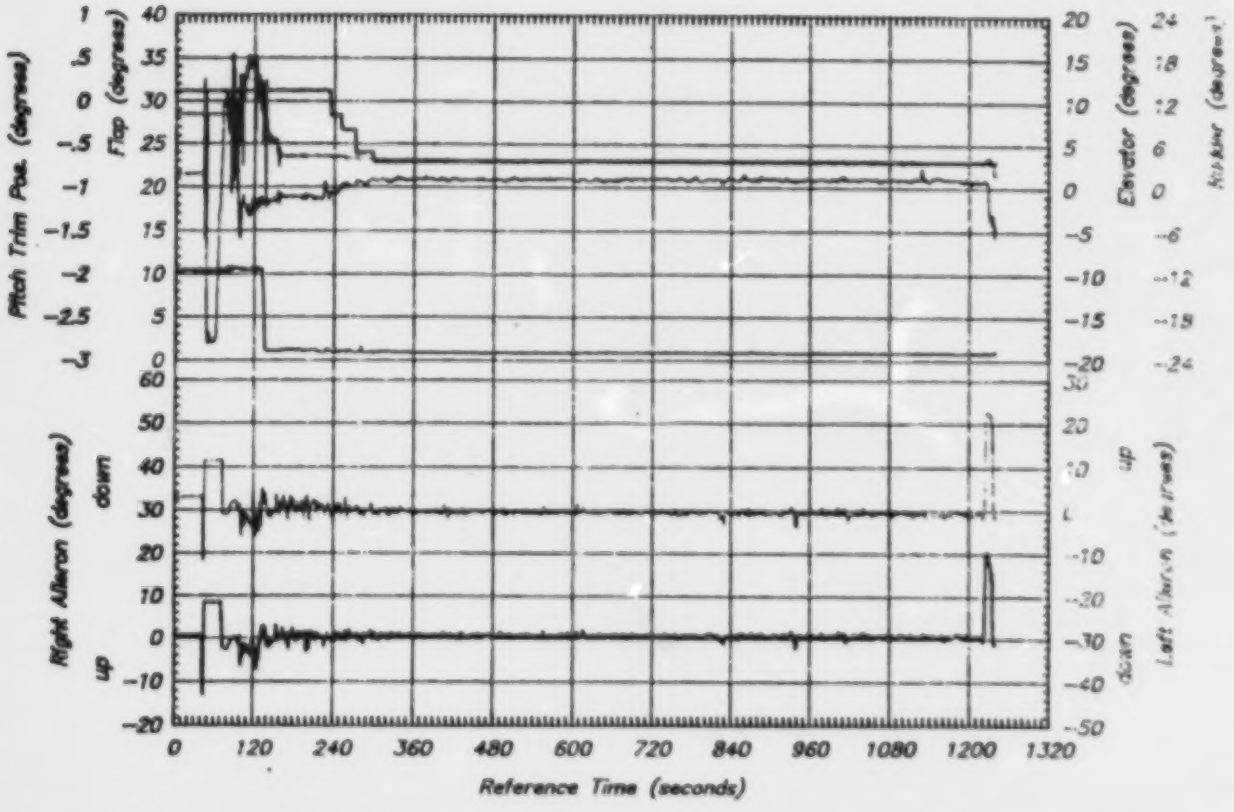


**Figure 1.4 FDR Recorded Control Positions and Airspeed**

## 1.11.2 Cockpit Voice Recorder

The CVR was a four-channel Fairchild A 100 recorder. The captain and first officer intercom, aircraft intercom, and cockpit area sounds were recorded. Once the engines were started, the voices of the crew members were drowned out. Notch filtering and adaptive filtering were unsuccessful in removing sufficient background noise to make crew conversations

intelligible when recorded by the cockpit area microphone. The voices of the crew members were recorded clearly when intercom was used. The complete accident flight was recorded.

Shortly after take-off from Montreal (about 15 minutes prior to the accident), the crew discussed a fuel system malfunction. From this discussion, it was apparent that a wing tip low-fuel-level warning indicator had illuminated; however, it could not be determined if this was a left or right indication or if a fuel imbalance existed. From the CVR, it was apparent that the crew was aware that the aircraft was speed-limited with this particular malfunction. The crew continued with the flight, and there was no further discussion or action on this issue.

Prior to take-off in Montreal, the captain stated that he intended to "hand-fly" the aircraft to Ottawa. During the flight, he twice commented that he was hand-flying the aircraft. About five minutes before the accident (941 RT), the captain stated "...this hand-flying is really tough to do."

It was apparent from the CVR recording that the pilots were taking note of various ground features they passed on their flight, noting the presence of airfields on their route.

Approximately one second prior to the maximum rate aileron deflection at the start of the accident sequence (1222 RT), the captain verbally indicated to the co-pilot that there was an airfield near where the aircraft was flying, stating "there's another little grass strip there." Nearly five seconds later, at 1226.7 RT, the co-pilot acknowledged this comment and, in the same breath, made an exclamation of surprise and concern. At the time of this exclamation, the FDR recorded aircraft roll attitude was approximately 90 degrees left. The co-pilot deactivated his intercom following this exclamation. At approximately 1230 RT, the altitude alert tone is heard on the intercom; at this time, the altitude loss recorded on the FDR is slightly more than 250 feet. Three seconds later, at 1233 RT, the co-pilot reactivated his intercom and, with increasing concern, twice cautioned the captain about the increasing aircraft speed. At this time, the aircraft had rolled through about 410 degrees, and the speed was increasing through approximately 250 knots. This was the last recorded intelligible comment from the cockpit prior to impact.

The first officer keyed his intercom "on" just before providing the last speed warning to the captain; no indication of the intercom being keyed "off" was noted. Just before impact, an unintelligible utterance was recorded faintly from both the cockpit area microphone and the intercom channel.

There was no indication from the pilots of a failure of any system or sighting of other traffic, nor were any unusual sounds recorded on the CVR. No warning from the GPWS was recorded.

## 1.12 Wreckage and Impact Information

### 1.12.1 Accident Site

The aircraft struck relatively flat pasture land which consisted of six inches of top soil over a homogeneous sand sub-base. Wreckage was also scattered into an adjacent sand pit. (Figure 1.5)

The wooded areas surrounding the pasture, back along the flight path, were searched for any wreckage; none was found.

### 1.12.2 Aircraft Impact

Aircraft breakup was extensive upon impact. From analysis of the ground scars, craters, and wreckage distribution, the aircraft attitude at impact was determined to be 41 degrees nose-down, with a bank angle of 86 degrees (left wing low); the final track was 197 degrees magnetic.

Pieces of the red lens cover from the left wing tip navigation light were found where the aircraft first struck the ground. From this point, a ground scar was made by the left wing for approximately 50 feet leading to three consecutive craters, the deepest of which was four feet. The three craters were caused by the impact of the left engine, the fuselage, and the right engine respectively. From the initial ground impact the wreckage was scattered over a 50-degree arc (maximum width of 300 feet) with the farthest piece, an aileron balance weight, thrown 785 feet.

Superficial soot and ash patterns observed indicated that a brief post-crash fire occurred following impact. There was no evidence of a pre-impact fire.

Figure 1.5 Aircraft Impact

1.12.3 Aircraft Wreckage

An inventory and reconstruction of the wreckage indicated that all major components and primary control surfaces were accounted for. All fuselage doors and hatches were located at the site. The entire right rear baggage door was still latched in its frame following the impact. All the wreckage was removed to the TSB Engineering Laboratory for analysis.

**1.12.4 Engines**

Engine identification was achieved by comparing component serial numbers from those in the engine log-books. All the major pieces of the engines and propellers were recovered within the confines of the wreckage scatter. Both engines were fragmented as a result of tremendous impact forces, and the damage to both was similar.

The following damage description applies to both engines. All propeller blades had pulled out of their respective hubs. The propeller pitch actuating cylinders were broken, exposing the blade actuating rods. The engine reduction gear cases, complete with the propeller hub, had separated from the engines. The high speed pinion shafts were twisted off in torsional overload. The low pressure and the high pressure impellers suffered extensive damage; they were exposed and separated from the rest of the engine parts. All the damage noted was impact related. The bending of the propeller blade actuating rods during impact also appeared to be similar, suggesting conformity in the operation of left and right engines.

The combustion cans were flattened, and several had come off the engines. The turbine sections were severely damaged as a result of impact. The damage to the turbines of both engines was similar and assessed as being typical of impact damage sustained with high rotational speed. No evidence of turbine pre-impact failure was noted.

Engine fuel system testing could not be performed because of the severe component damage.

No pre-impact failures were noted on the engine. The damage to the rotating components, shafts, and tie bolts indicated that impact occurred while the engines were operating at a relatively high rotational speed.

**1.12.5 Systems Examination**

The severe destruction of the aircraft did not allow analysis of many of the aircraft systems and instruments. No light bulbs were recoverable for analysis. The following instrument information was obtained:

> Engine torque gauge: instrument was indicating 525 pounds per square inch (psi). There was no indication as to which engine this gauge was from.

Rate of climb: both instruments were found and were indicating 2,000 feet per minute (fpm) down (maximum down).

Airspeed indicator: the indication was over the red line and was estimated at 270 KIAS; it was not determined whether this instrument was from the pilot or co-pilot panel.

Analysis of the hydraulic system was not possible. Some fluid was present in wreckage components, but pre-impact fluid quantity and pressure could not be determined. The landing gear was determined to be up at the time of impact.

The autopilot servo-motors and actuators were disassembled. All damage was consistent with the servo-motors being stopped at impact.

The aircraft was equipped with a Sperry FPZ200 flight director. Not enough of the flight director was recovered to make any determination as to its operational state at impact.

**1.12.6 Elevator, Rudder and Flap System**

There were no identifiable pre-impact failures or malfunctions of the elevator system. The right horizontal stabilizer and elevator were relatively intact. The stabilizer was severely crushed rearward from the leading edge, and the aft edge was popped open from about three feet outboard of the root to the tip. The elevator had crush damage on the leading edge. It was also covered in soot from a post-impact ground fire.

The left horizontal stabilizer and elevator were broken into eight large pieces. It was determined that the entire stabilizer and elevator assembly was present at the time of impact. There were no pre-impact failures identified.

There were no impact capture marks that would indicate the position of the elevators at impact. The control push rods were examined and determined to have been serviceable before impact. There were no faults identified in the gust-lock system.

The vertical stabilizer leading edge was crushed back about eight inches. The rudder was wrinkled and crushed and showed some fire damage from the post-impact flash fire. There were no faults found in the rudder system.

All sections of the flap and all the flap tracks were found, although the exact track locations could not be identified. Roller marks on the flap tracks or mechanism trapped in some tracks indicated that the flaps were up at impact.

### 1.12.7 Lateral Control System Examination

Because of the massive destruction of the aircraft, it was not possible to demonstrate conclusively complete control system continuity; however, no faults with the system were found. Both control wheels were found, as well as parts of both control columns. Many of the pulleys and bell-cranks from under the cockpit floor were found; however, identification of many parts was not possible. There was no indication on any of the parts of a pre-impact unserviceability or failure. All control cable failures were overload in nature. The tension regulator, which automatically controls the tension of the fuselage cable loop, was found. There were no pre-impact faults identified with this unit. It could not be determined what the pre-impact tension on the fuselage cable loop was.

Both ailerons, although broken up, were found at the accident site. The damage pattern showed that the left aileron was slightly down at impact; the deflection of the right aileron could not determined from the wreckage. The wing bell-cranks and push rods for each aileron were found and identified. The primary aileron stops were still attached to the right aileron bell-crank. The pivot shaft was slightly bent so that bell-crank movement was restricted except in the mid-travel range, from about five degrees off the up stop through 40 degrees of travel to about 50 degrees from the down stop. Even with this restriction, it was still possible to move the bell-crank through its full range of travel. Both stops had rubber caps in place. These caps were not cut or torn. Both aileron attachment brackets were found. All failures were impact related. All aileron hinges were located, and no pre-impact faults were identified with the hinges.

Recovered fairleads were checked for correctness of orientation on their cables and structure. Only impact damage was noted.

All aileron cables from both wing loops were recovered, their turnbuckles were identified, and turnbuckle lockwiring was found to be intact. The turnbuckles were measured, and it was found that the left pull-up cable turnbuckle was 0.27 inches longer than a correctly rigged HS 748-2B sample aircraft examined at the manufacturer's plant. The right turnbuckle was

very close in length to manufacturer's sample. A longer turnbuckle can indicate a cable with less tension, if other variables, such as cable manufactured length, are constant.

Both aileron operating rod assemblies (P/N 1R.4988) were found and examined. The rod end of the left aileron operating rod had 15 exposed threads; whereas, the rod end of the right aileron had only 3 exposed threads. The rod ends are used to adjust aileron angle in the rigging process. Each turn out, that is, one thread, raises the aileron 0.75 degrees. The left operating rod was adjusted to be longer than the right rod.

The manufacturer measured the threads of the operating rods on two HS 748 aircraft at their plant and found that these rods had measurements ranging from 6 to 11 exposed threads (left rod end samples 6 and 7 threads, right rod end samples 8 and 11 threads). Both the left and right operating rods are designed to have the same pre-adjusted length.

The operator provided the thread counts of the control rods of aircraft in its fleet (all aircraft had successfully passed the Notice to Operators (NTO) No. 5 handling test and were assumed to possess nominal rigging). The control rod thread counts for the aircraft measured are given below:

Operator HS 748 Control Rod Thread Counts

| Left | Right |
|---|---|
| 10.5 | 10.5 |
| 6.0 | 6.5 |
| 7.0 | 7.0 |
| 5.5 | 11.5 |
| 6.0 | 10.0 |
| 8.0 | 9.5 |
| 11.0 | 11.0 |

Both control rod assemblies (P/N 1R.4746) were located and their relative lengths measured. The control rod assemblies connecting the outboard cable quadrant of the ailerons to its respective bell-crank, which allows adjustment to the aileron rigging, were recovered (the clevis end of the control rod can be rotated in or out, thereby shortening or lengthening the rod). The right control rod clevis had been adjusted out 4.33 turns more than the left control rod clevis; the right control rod was, therefore, the longer by 0.21 inches. Lengthening the control rod causes the aileron to move up.

## 1.13 Medical Information

### 1.13.1 The Captain

The captain had suffered from mild allergies since childhood. This condition was easily controlled by the use of antihistamines. Allergies were mentioned in every aviation medical between 1969 and 1987; however, only in 1969, was treatment in the form of antihistamines mentioned. The last time the allergies were mentioned, there was a Medical Examiner's comment recorded on the report that stated "Allergy is not troublesome." Other than surgery for the removal of his gallbladder in 1985, there was no indication of medical problems experienced by the captain.

The captain was known to be a happy, well-adjusted person who got on well with other people and showed no signs of depression. No evidence was found to indicate that the captain had been subjected to any psychologically reactive events in the 72- or 24-hour periods prior to the accident.

### 1.13.2 The First Officer

The first officer was mildly asthmatic since early childhood; he took no medication for this condition. He had suffered from significant deviations of the nasal dorsum and septum, a condition that could have been corrected by surgery. Because this condition did not significantly interfere with his breathing, he did not seek treatment. The first officer had, from time to time, suffered from recurring ear infections. He was last treated for this condition in October 1986. Medication for this condition was found in his apartment, but, apparently, he had not required the medication for some three or four months prior to the accident.

The first officer was physically very active, participating in bicycle riding, some hiking, and camping. His medical examinations indicated that his blood pressure was usually in the low normal range.

The investigation indicated that the first officer was socially active and got on well with everyone. He had no history of psychological problems and, prior to the accident, did not exhibit any abnormal mood, personality or behavioural changes. In general, he was known to be a happy, outgoing and well-adjusted person who showed no signs of depression. No evidence was found to indicate that the first officer had been subjected to any psychologically reactive events in the 72- or 24-hour periods prior to the accident.

### 1.13.3 Autopsy and Pathology

Because of the nature of the trauma suffered, autopsy and pathological information was very limited. Toxicological screening for alcohol was negative for both pilots.

### 1.13.4 Summary

There was no evidence that incapacitation or psychological factors affected the crew's performance. No evidence of physiological factors was found, other than possible fatigue. (See Section 1.17.10)

## 1.14 Fire

On impact, the wing fuel tanks ruptured, and fuel was sprayed along and to both sides of the wreckage trail. This fuel was ignited and burned a grass area approximately 250 feet long by 150 feet wide. The fire burned in this area for a period of two to three minutes. After this time, only several small localized fires remained, and these burned for another 10 to 15 minutes. Because of the short duration of the fire, the aircraft wreckage sustained only minor fire damage.

## 1.15 Survival Aspects

It was determined from the analysis of the belt material that both pilots had their seat-belts fastened during the accident. Only one pilot's shoulder harness was fastened, but it could not be determined which of the pilots was using his shoulder harness.

Both crew members were fatally injured on impact. The impact forces were beyond the limits of human tolerance.

## 1.16 Tests and Research

### 1.16.1 Simulations

A series of simulations were conducted using the manufacturer's Hatfield, U.K. simulator, programmed to have different control-wheel force gradients. For each control-wheel force set-up, attempts were made to re-create the accident trajectory by aileron and elevator control inputs at times indicated by the accident FDR. The tests were "flown" by a TSB investigator, by the accredited representative from the U.K. Air Accidents Investigation Branch (AAIB), and by a pilot from British Aerospace (BAe) who had previously flown the HS 748.

The simulator has a generic cockpit and is used to simulate several of the manufacturer's products. The aileron wheel force model simulated the normal force gradient with peak wheel force of about 49 pounds, which peaks at an aileron angle of 11.5 degrees (two-thirds travel), then reduces to 28 pounds at the maximum aileron deflection. Two other force gradient models were also used. One had a peak force of 34 pounds, peaking at nine degrees and lessening to zero pounds at maximum deflection. The other was an overbalance condition with a peak force of 30 pounds at 7.5 degrees deflection and a negative force (overbalance) of 20 pounds at full deflection. The simulator did not increase the wheel forces with increasing airspeed, as would be the case with the aircraft.

The aerodynamic properties of the simulator were not exactly those of the HS 748-2B, but the manufacturer estimated that roll performance would be very similar.

The results of these tests were as follows:

Roll rate was very close to that observed in the FDR read-out.

A rate of descent was first apparent on the vertical speed indicator (VSI) just prior to the relative time of application of elevator observed in the accident flight.

For the wheel force conditions other than the overbalance case, maintaining aileron force to cause a roll was difficult.

The accident manoeuvre is confusing for a pilot not trained in aerobatics.

### 1.16.2 Test Flights C-GBFA

#### 1.16.2.1 Introduction

A test flight was carried out using the sister ship to the aircraft involved in the accident. This was the HS 748-2B that left the U.S. maintenance facility with the accident aircraft's original factory-installed left aileron substituted for its own. The purpose of the tests was an evaluation of the aileron control wheel forces and comparison of control-wheel position and measured aileron angle.

The test points were flown by a Transport Canada test pilot with a TSB investigator observing and recording the tests with a hand-held video camcorder.

Control-wheel force was determined by the use of a hand-held force gauge. The gauge measured peak force only, and force correlation with wheel displacement was not possible.

The control-wheel tests followed the instructions contained in the HS 748-2B Maintenance Manual, Chapter 27-10-0, for flight test following aileron repair or change. The aircraft was flown at 120 KIAS and 155 KIAS (the Maintenance Manual flight test airspeed is 155 KIAS which equals $V_A$) for full deflection tests. Tests using 2/5 control deflections were conducted at 200 KIAS and 225 KIAS (the Maintenance Manual test airspeed is 225 KIAS). The tests were flown at an altitude of 4,000 feet. In trimmed level flight, the control wheel was displaced slightly left (about 5 per cent of full deflection).

The FDR from the test aircraft was removed for read-out by the TSB Engineering Laboratory following the flight. The movement and the initial rigged position of the ailerons were measured using a digital protractor, with the aircraft parked, after the flight.

### 1.16.2.2 Full Deflection Tests at 120 KIAS and 155 KIAS

Each rapid control-wheel movement to maximum deflection resulted in positive restoring force back to neutral. At 120 KIAS, the peak control-wheel force measured with a left-wheel application was approximately 45 pounds; right-wheel force was about 57 pounds. At 155 KIAS, the peak force in the left-wheel direction was about 55 pounds and 54 pounds in the other direction.

The test pilot noted a slight lightening of control forces in the right-wheel direction near the maximum deflection, but a positive restoring force back to wheel neutral was present.

### 1.16.2.3 Partial Deflection Tests at 200 KIAS and 225 KIAS

Following successful completion of the tests at 155 KIAS, partial control-wheel tests were conducted at 200 KIAS and 225 KIAS. At 200 KIAS, the 2/5 left-wheel deflection resulted in a measured wheel force of about 35 pounds; right control-wheel force was 37 pounds. The 225 KIAS tests yielded a left-wheel force of about 41 pounds and right-wheel force of 36 pounds.

The 200 KIAS, 2/5 wheel-deflection forces were about 20 per cent greater than the same deflection at 155 KIAS. The measured 225 KIAS 2/5 left-wheel force was 46 per cent greater than the 2/5 defected force at 155 KIAS. No lightening tendency was noted in the control-wheel forces during the 2/5 deflection tests.

The test flight aircraft would have passed the Maintenance Manual/NTO No. 5 flight test. Previously, the operator had successfully completed the same test as part of fleet-wide inspection of their HS 748 aircraft following the 15 September 1988 accident.

**1.16.2.4 Test Aircraft Aileron Response**

The FDR from the test aircraft recorded increased downward movement of the right aileron neutral position, compared to left aileron, with increasing airspeed. The right aileron moved down approximately 1.8 degrees, and the left aileron moved down nearly 1.0 degrees.

**1.16.2.5 Test Aircraft Aileron Rigging**

The initial rigged (gust-locked) aileron positions measured on the test flight aircraft were as follows: left aileron rigged 0.8 degrees up from the chord line; the right aileron was rigged 1.4 degrees up from the chord line (normal rigged position is 1.5 degrees up). Full aileron travel was found to approximate the normal range of 18.5 degrees up and down for both ailerons, from the gust-lock neutral position on the ground.

When the test aircraft (Constructors No. 1791) was first flight tested following manufacture in 1981, some "flying control adjustments" were made. The net result of the adjustments was "port aileron trim tab screwed in 2 and 1/2 turns."

**1.17 Additional Information**

**1.17.1 Other Traffic**

None of the witnesses recalled seeing any other aircraft in the vicinity of the HS 748 at the time of the accident. This was also supported by an examination of the Montreal radar tapes and observations by air traffic controllers in Montreal and Ottawa. There was no indication of traffic that could have conflicted with C-GFFA.

**1.17.2 Accident Site Overflight**

An aerial survey of local grass strips in the vicinity of the crash site was carried out. A small, newly constructed strip was located approximately 1.5 nm east of the crash site and slightly left of the estimated flight path of the aircraft. The airstrip was easily observed while flying on the estimated track of the accident aircraft. This was the only airstrip found near the accident site which would have been readily

visible to the captain at the time of his remark regarding the sighting of an airstrip, to the co-pilot, just prior to the accident sequence. The captain would have been able to see the airstrip to his left and back along the aircraft track at the time of the remark.

### 1.17.3 Aileron Performance

#### 1.17.3.1 Manual Controls

Aircraft designers employ the use of manual controls whenever the speed regime and size of the aircraft allow. By using manual controls, the aircraft systems can be simplified. Hydraulic-powered flight control systems, with their plumbing, actuators, and redundancy requirements can add weight and complexity. Manual control systems, in order to keep control-wheel forces light enough for pilots, often use aerodynamic balance designs. Offset hinged ailerons, horn balance, and lagging gear tab provide the aerodynamic balance on the HS 748. Manual flight controls must be carefully designed, particularly as the speed range of the aircraft increases, to ensure that there is not an overbalance control force. In other words, the control force would be too light or the aileron could actually be held fully deflected against the pilot's wishes.

#### 1.17.3.2 Control Force

The early versions of the HS 748 (Series 1, 2, and 2A without Modification 3723 or 4080) had ailerons rigged to fair along the chord line of the wing. This aileron neutral position, however, changed with the introduction of Modifications 3723 and 4080. With Modification 3723 embodied, Series 1, 2, and 2A were required to have an aileron neutral setting of 1.5 degrees above the wing chord line, and a tab setting 2.5 degrees down from the aileron at its neutral setting. With Modification 4080 embodied, Series 1, 2, 2A and 2B aircraft were required to have an aileron neutral setting of 1.5 degrees above the wing chord line, and a tab setting in line with the aileron at its neutral setting. The purpose of the aileron up-rigging modifications was to change the bending moment distribution in the wing and thereby allow an increase of aircraft zero fuel weight.

The aircraft manufacturer provided aileron hinge-moment data to the TSB. Plotting these data, with various assumed symmetrically rigged aileron positions, showed that, as the ailerons are rigged further above the chord line, peak control force is reduced and the peak occurs with less wheel deflection. For example, at 200 KIAS and 3,000 feet asl, with the ailerons rigged at zero degrees relative to the chord line, the peak wheel

force is approximately 58 pounds which occurs at 12 degrees deflection. At the normal rigged position of 1.5 degrees up from the chord line, the peak force is 48 pounds at 11.5 degrees deflection. For ailerons symmetrically rigged at 3.5 degrees up from the chord line (the maximum up adjustment permitted is 1.5 degrees, plus 2 degrees), the calculated peak wheel force reduces to 33 pounds occurring at approximately 10 degrees.

The manufacturer indicated that the drag reduction seals have a negligible effect on aileron performance and control forces.

**1.17.3.3 Aileron Overbalance**

Aileron overbalance is an aerodynamic phenomenon sometimes encountered with horn balanced and offset hinge balanced control surfaces. It is a dangerous condition that can occur with some designs when the control surface is deflected to a high angle. In essence, the control surface aerodynamic hinge moment reverses and takes the surface from the pilot's command, to an uncommanded higher angle, and holds it there. The pilot must, in some occurrences of control overbalance, use considerable strength to force the control surface back towards neutral. This phenomenon is also known as aileron lock.

For the HS 748 with an aileron deflection greater than 18.5 degrees down from the chord line, the aerodynamic hinge moment of a single aileron acting alone becomes downwards acting and large enough to hold the aileron down. At angles greater than 20 degrees up, the hinge moment of a single aileron acting alone, becomes upwards and is large enough to hold the aileron up. If, because of misrigging, both the up and the down ailerons reach excessive angles, or if the sum of forces provided by asymmetrically rigged ailerons is not balanced to provide a restoring force, the aileron system can become aerodynamically overbalanced. The hinge-moment curves have steep slopes at the extremities of aileron travel. A small change of aileron angle produces a large change in control force.

With asymmetric rigging of 3.4 degrees (left aileron up 3.0 degrees, right aileron down at 0.4 degrees, relative to the chord) and normal aileron cable tension, aileron overbalance will occur at 200 KIAS (Figure 1.6). With the control wheel left, the maximum force will be reached at approximately half deflection; the peak force will be about 51 pounds. With 20.25 degrees of aileron system deflection, derived from the normal system travel of 18.5 degrees plus 1.75 degrees (the average of the 2.3 degrees right aileron and 1.2

left aileron extra travel as measured by the FDR), an overbalance force of about 37 pounds would hold the ailerons deflected at 200 KIAS (after considering about 17 pounds of positive assistance provided by Modification 4080 centring springs in the system). Based on the hinge-moment data provided by BAe, TSB investigators calculated that, at 225 KIAS, and at the same 20.25 degrees of aileron system deflection indicated by the FDR, the overbalance force would be 52 pounds; at 250 KIAS, the force would be 68 pounds.

The preceding calculations have uncertainties because hinge-moment curves provided by the manufacturer are theoretical and are not based on measured or test data. In addition, because of the slope of the hinge-moment curves at large deflection angles, the change of the overbalance force with the change of aileron angle is rapid. At 200 KIAS, in the range of maximum aileron deflection angles, each 1.0 degree change of aileron angle equates to approximately 20 pounds of overbalance force for the given conditions of 3.0 up-rigged left aileron and 0.4 degree down-rigged right aileron. Any increase in the rigging asymmetry increases the overbalance force and the rate of change of the force with aileron deflection.

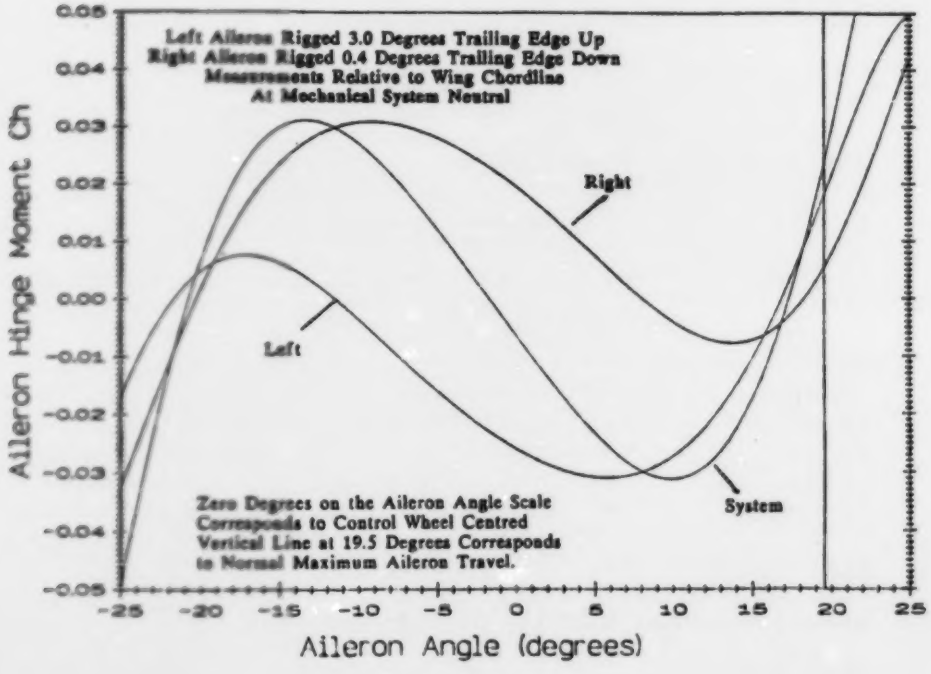


**Figure 1.6 Aileron Hinge-Moment Characteristics (Left Aileron 3.0 Degrees up Right Aileron 0.4 Degrees down)**

### 1.17.3.4 Aileron Float Down

The FDR data shows that the left aileron neutral position of the accident aircraft moved down from the gust-lock neutral position as airspeed increased. The right aileron shows very little movement from the neutral position. The aircraft manufacturer was asked to comment regarding this observed performance.

According to BAe, the observed performance is consistent with asymmetric rigging of the left and right ailerons, with the left aileron rigged higher than the right. Symmetrically rigged ailerons, at 3.5 degrees up from the chord line, would each "float down" 2.3 degrees. However, with the left aileron initially rigged higher than the right, the aircraft would tend to roll left if the control was held centred. The pilot would then move the control wheel to the right to compensate in order to keep the wings level. This control action would move the right aileron back up, but the left aileron would move further down. At a steady speed trimmed state, the control wheel would be trimmed to the right and the right aileron ends up in the same position in cruise, as it was in the gust-lock neutral position. BAe indicated that the amount of asymmetric rigging would be approximately equal to the observed float down. The company indicated that other effects such as trimming for fuel imbalance would account for only 1/2 degree of float.

Normal symmetric aileron rigging of 1.5 degrees above the chord line produces aileron angles of -0.1 degrees to -0.7 degrees (down, relative to the chord line) when flying at 200 KIAS.

### 1.17.3.5 Effect of Asymmetric Aileron Rigging

Because the aileron stops are located on mechanism prior to the final adjustment point of the aileron, the adjustment of the aileron operating rod and the stops determine the maximum control surface deflection. For example, if the left aileron was rigged up 3.5 degrees (2.0 degrees greater than normal), then the full aileron deflection would be 22 degrees up from the chord line (23 degrees if the aileron stop allows 19.5 degrees of travel). According to the manufacturer, with asymmetric rigging, the increased full aileron travel would "have a significant effect on locking-on".

### 1.17.4 Aileron System Maintenance Procedures

Aileron system maintenance practices are contained in the HS 748 Maintenance Manual, Chapter 27-10-0. The progression of the information presented is from

"Removal/Installation", followed by "Adjustment/Test." The procedure for the removal of an aileron is short, consisting of marking the neutral setting for future refitting, accessing the aileron hinges, and disconnecting control rods and hinges.

Installation procedures for the aileron include instructions for the user to "check and set aileron trim and balance tab ranges in accordance with Chapter 27-10-0, Adjustment/Test, Page Block 501." A note is included with this instruction: "If the aileron is being fitted after a minor rectification it must be set at the neutral setting obtained in 1. AILERON REMOVAL."

The Adjustment/Test section of 27-10-0 guides the user through the entire aileron system rigging, including cable tensioning, the setting of each aileron with its tab system, and adjustment of the quadrant stops.

The Adjustment/Test section includes guidance regarding airtests following maintenance to the aileron system and methods to achieve acceptable control forces. If by airtest, the control forces at 155 KIAS are assessed as "too light and/or the ailerons remain at full travel on release", then the ailerons are to be adjusted downwards, but not below 1.5 degrees up relative to the wing chord line. If adjustment below the 1.5 up-rigged position is required for satisfactory (heavier) control forces, further instructions are given directing the user to contact the manufacturer's Product Support Department for advice. According to the manufacturer, the fitting of Flettner strips could be used to provide heavier aileron control forces. The manufacturer knew of no circumstances where a customer had been counselled to use the Flettner strips; however, two aircraft left the factory so equipped.

In the event that the aileron control forces are too heavy at 155 KIAS, the aileron neutral position can be rigged up a maximum of two degrees above the 1.5 up neutral position, relative to the wing chord.

For adjustment of the light control forces at 225 KIAS, the aileron rigging is to be adjusted downward in the same manner as for the adjustments for forces at 155 KIAS.

When control forces are too heavy at 225 KIAS, then the user is directed to adjust the aileron tabs symmetrically downward within the permitted tab rigging tolerances in two-degree increments (1 and 1/2 inward turns of tab rod eye-end adjuster).

The "Adjustments Following Flight Test" section does not contain specific guidance to users to readjust

control stops following rigging changes. No specific instructions are contained in this section guiding the user back to check control cable tensions.

**1.17.5 Flight Test Requirements**

Both the HS 748 Maintenance Manual and the BAe NTO No. 5 for the HS 748 aircraft, dated 01 March 1984, detail when test flights are to be carried out after maintenance work on the ailerons and what the flight test procedures are. The description of the flight test procedures is consistent in both documents; however, the description of when these flights are required is ambiguous. The Maintenance Manual states "when an aileron is changed or repaired, or if the aileron or aileron tab rigging has been adjusted for any reason, then a flight test should be carried out as detailed below." (Underlining added)

NTO No. 5 states at paragraph 1 that the full application of ailerons check is required on the test flight following an aileron change, repair, or adjustment, and at paragraph 5 that, when an aileron or tab is changed or repaired, an aileron handling flight test must be completed. Discussion with the operator and other operators showed that the necessity for the airtest was not clear to them and was subject to interpretation. To some, the word should suggests a recommended practice only, with no obligatory action required.

The Maintenance Manual was amended by Transmittal 1245 in June 1985 to incorporate NTO No. 5. NTO No. 5 was not cancelled. The Maintenance Manual procedure (27-10-OEL, 30 September 1984) to be carried out on the aileron flight test is as follows:

> At 155 knots I.A.S., flaps retracted and the aircraft carefully trimmed, check that the aileron wheel forces are normal as half wheel travel is applied. If this is satisfactory, a full wheel travel check is required. This should be checked by first establishing a 25 deg. bank turn in the opposite direction to the intended full aileron wheel application. Having established the turn, rapidly apply full aileron and then release. Check that the handwheel returns towards the central position as, or before, the aircraft reaches the approximate wings level attitude. Repeat this check in the opposite direction.
>
> If the aileron forces are too light and/or the ailerons remain at full travel on release, do not proceed with any further aileron handling checks until after adjustments have been made.

When the full aileron handwheel check is satisfactory, increase speed to 225 knots I.A.S. When established at the correct airspeed with the aircraft in trim, apply up to 2/5 aileron wheel travel and ensure that a heavy two-handed force is required. The checks must be done at altitudes below 15,000 feet.

After the accident, the operator test flew all their HS 748 aircraft to verify that aileron performance was in accordance with the Maintenance Manual and NTO No. 5. Of the nine aircraft test flown (eight 2A models and one 2B), three 2A models did not meet the specifications. In all three cases, the ailerons did not return toward the central position on their own following the application of full aileron. Only light wheel force was required to restore the aileron to neutral; the maximum estimate of control-wheel force was 10 to 15 pounds. One of the operator's aircraft required several airtests to complete the NTO No. 5 test successfully. Five months later, this same aircraft failed the NTO No. 5 test, only a few days after the test had been demonstrated successfully during flight training. Maintenance action consisted of a small aileron control rod adjustment of one-half turn (which results in only a 0.375 degree change in aileron position) and retensioning of aileron control cable wing loops. The control wheel returned toward neutral, on a subsequent NTO No. 5 airtest.

The pilots conducting the NTO No. 5 type airtests flights noted that the ability of the ailerons to restore to the neutral position, following the release of control wheel, appeared to be related to aircraft speed. An aircraft would "pass" the test at airspeed values less than those where the wheel would not restore to neutral. In all three cases, the pilots reported that heavier control forces were required for aileron application after rerigging had been completed. The manufacturer indicated that the ability to meet centring requirement of NTO No. 5 varies with speed as the return spring force is more significant at lower speeds as the aerodynamic forces are smaller.

All operators of the HS 748 aircraft in Canada were contacted to determine whether they had encountered any aileron control problems in flight. There were seven operators, other than Bradley Air Services, operating a total of 20 HS 748 aircraft. None of these aircraft is a 2B model. Only one other operator indicated that one of their aircraft failed to pass the NTO No. 5/Maintenance Manual airtest.

The failure of the control wheel to restore toward neutral, during the NTO No. 5/Maintenance Manual flight test, means that the aileron rigging on that HS 748 has allowed aileron overbalance.

The manufacturer indicated that an aircraft could pass the NTO No. 5 test and still have aileron overbalance occur at a higher speed. For example, if the NTO No. 5 test at 155 KIAS was passed with a restoring wheel force approaching zero, aileron lock would occur with full aileron deflection at 200 KIAS (full aileron deflection is not permitted as $V_A$ is 155 KIAS). The overbalance force at the control wheel would be approximately 10 pounds.

The manufacturer also indicated that the passing or failing of the NTO No. 5 test can depend on the rate of application of aileron near the stop position. This fact is not included in the NTO No. 5 or Maintenance Manual airtest instructions.

A representative from the U.K. Civil Aviation Authority (CAA) was not aware of any other aircraft that required an NTO No. 5 type airtest to verify aileron performance. He also indicated that, during annual airtests of selected HS 748 aircraft, done to verify production/in-service performance, the NTO No. 5 test is not conducted.

### 1.17.6 Information Available regarding Aileron System

#### 1.17.6.1 Documentation

The following documents contain information on the HS 748 aileron system and operation: the HS 748 Flight Manual, the HS 748 Crew Manual, the HS 748 Maintenance Manual, and NTO No. 5. It should be noted that, of these four documents, only the first two are aircrew documents. The latter two are primarily maintenance and maintenance flight test documents which were not readily available to aircrew. The NTO No. 5 does have the following statement on its cover page: "IMPORTANT: THE CONTENTS OF THIS NOTICE TO OPERATORS MUST BE BROUGHT TO THE ATTENTION OF ALL PILOTS AND AIRFRAME MAINTENANCE PERSONNEL"; however, the operator did not distribute the NTO No. 5 to all pilots.

These documents contain references to lightening of the aileron control forces, aileron rigging adjustments, aileron "lock-on", and aileron limitations. The Flight Manual, under "Airspeed Limitations" states "manoeuvres likely to involve full application of the primary flying controls shall not be attempted at a speed greater than 155 knots ($V_A$)." The Crew Manual at

paragraph 1B, page 1, Chapter 10 states "the quadrant assembly is spring loaded to prevent lock-on of the aileron at full travel in flight." Of interest is the fact that NTO No. 5 specifies aileron application limits for the 2A and 2B models of full aileron at 155 knots ($V_A$), 2/5 aileron at 225 knots ($V_{NO}$), and 1/5 aileron at 260 knots ($V_{NE}$); however, these latter two limits are not specified in the Flight Manual. The manufacturer stated that these limits are based on structural considerations, not aircraft handling qualities.

There were changes from the original NTO dated 01 February 1974 to the amended version dated 01 March 1984. In particular, paragraph 2 of the original NTO contained the following statement which was not included in the amended version: "HSA are concerned that with the increasing number of aircraft which may have had ailerons changed or re-rigged in service, there may be aircraft flying with aileron wheel forces considerably lighter than those originally cleared by HSA."

There are no warnings in the Flight Manual or Crew Manual regarding the possibility of aileron aerodynamic overbalance or "lock". No information is contained in the Flight Manual as to the procedures to be followed if aileron "lock" is encountered. Operators from Canada and the U.K. were generally unaware of the reasons for the aileron performance flight test.

According to the CAA, the purpose of the NTO No. 5/Maintenance Manual aileron flight test is to "heavy" the controls to make it less likely that pilots will apply large aileron control inputs at speeds above $V_A$. This test was stated to be essentially for structural and not handling considerations.

### 1.17.6.2 Compliance Requirements

Discussions with Transport Canada officials indicate that there is some uncertainty concerning the NTOs regarding operator compliance requirements. Airworthiness Manual Advisory (AMA) 571.101/4 in paragraph 5 (d) states:

> Although manufacturer's recommendations are not formally approved, they are assessed by the DOT to determine their acceptability. Programs based upon manufacturer's recommendations therefore, will generally be approved after a minimum of investigation, provided that all necessary additional items resulting form the operator's role, environment and optional equipment are also included.

> It should be noted that the term "manufacturer's recommendations" is not limited to the basic recommended schedule. The manufacturer often makes additional recommendations in service bulletins, service letters, letters to operators, etc., and all these should be taken into account, as should those of engine, propeller and appliance manufacturers. Service bulletins and similar documents then, are treated in the same manner as the other manufacturer's recommendations. They have the same authority as the maintenance manual.

There were differing opinions among Transport Canada officials about whether the NTOs could be considered to be "manufacturer's recommendations".

Letters-to-Operators, including NTOs, are usually only reviewed by Transport Canada if a specific request to do so is received from an operator. There is no indication that NTO No. 5 was assessed by Transport Canada.

**1.17.7 Roll Incident**

A pilot, employed by the operator, described an experience encountered in an HS 748 that related to aileron control. Several months prior to this accident, as part of a handling exercise, he spontaneously decided to apply full right aileron at about 210 KIAS. He noted that the ailerons were hard over and that force was required to return the control wheel toward neutral. The magnitude of the force was not estimated, but the pilot indicated that he had to shift the position of his hands to provide the necessary force. The manoeuvre was initiated with 30 degrees of left bank on the aircraft; aileron control was not achieved until 60 degrees of opposite (right) bank was reached. Records indicate that this aircraft was one of the operator's three aircraft which did not pass the NTO No. 5 test conducted after the accident. A right aileron down rigging of 1.5 degrees (2 turns in adjustment) was required for successful completion of the aileron response test.

**1.17.8 Control Forces**

**1.17.8.1 Certification**

Several U.S. Federal Air Regulations (FAR) in force at the time of certification (amendment 20) addressed the certification of control systems, including design and response.

FAR 25.671 described "General" considerations as follows:

(a) Each control and control system must operate with the ease, smoothness, and positiveness appropriate to its function.

(b) Each element of each flight control system must be designed, or distinctively and permanently marked, to minimize the probability of incorrect assembly that could result in the malfunctioning of the system.

(c) Each tab control system must be designed so that disconnection or failure of any element at speeds up to $V_C$ cannot jeopardize safety.

(d) Each adjustable stabilizer must have means to allow any adjustment necessary for continued safety of the flight after the occurrence of any reasonably probable failure of the actuating system.

Amendment 38 to FAR 25.671 paragraph (c) states the following:

(c) The aeroplane must be shown by analysis, test, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and feel systems) within the normal flight envelope, without requiring exceptional piloting skill or strength. Probable malfunctions must have only minor effects on control system operation and must be capable of being readily counteracted by the pilot.

(1) Any single failure not shown to be extremely improbable, excluding jamming, (for example, disconnection...

(2) Any combination of failures not shown to be extremely improbable, excluding jamming...

(3) Any jam in a control position normally encountered during take-off, climb, cruise, normal turns, descent and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such a runaway and subsequent jamming is not extremely improbable.

FAR 25.675 (Amendment 20) described control "Stops" as follows:

(a) Each control system must have stops that positively limit the range of motion of the control surfaces.

(b) Each stop must be located so that wear, slackness, or take-up adjustments will not adversely affect the control characteristics of the airplane because of a change in the range of surface travel.

(c) Each stop must be able to withstand any loads corresponding to the design conditions for the control system.

**1.17.8.2 Normal Design Forces**

Requirements to which HS 748-2B was certificated were as follows:

| BCAR | FAR | |
|---|---|---|
| Not excessive (which was interpreted as maximum that could be applied with one hand taking into account cockpit configuration.) | Aileron<br>60 lb | Elevator<br>75 lb |

Note: The above are one-handed forces, two-handed forces are not quoted.

The reference "Aircraft Stability and Control for Pilots and Engineers" gives various maximum force values demanded from a pilot using a control wheel. These wheel forces (in pounds) are as follows:

| | Aileron | Elevator |
|---|---|---|
| Maximum all out effort for very short time: | | |
| Using two hands | 120 | 220 |
| Maximum permissible force for short time: | | |
| Using two hands | 80 | 110 |
| Using one hand | 50 | 70 |
| Maximum comfortable force for short time: | | |
| Using two hands | 30 | 40 |
| Using one hand | 20 | 30 |

### 1.17.8.3 Elevator Force During Accident Sequence

Using basic aerodynamic data from the manufacturer, elevator stick force was calculated for points in the accident sequence.

The elevator was first applied at 1228 RT, approximately four seconds following the commencement of the roll to the left. During the roll, the elevator deflection recorded varied from three to about five degrees. These elevator deflections would have required approximately 110 to 150 pounds of wheel back pressure.

### 1.17.9 Maximum Flight Duty Time

Air Navigation Order (ANO) Series VII, No. 2 legislates the maximum allowable flight and duty times for operators of large aircraft (mass greater than 5,700 kilograms).

The operator is obliged to establish a system that establishes maximum flight time, maximum duty time, and a minimum rest period for its flight crew members for each 24-hour period. Many factors are to be considered in the system, including arrival and departure time of flights and the probability of operational delays occurring during the flights to which flight crew members are assigned.

The Transport Canada approved Operations Manual for use by the operator described the flight and duty times limitations in force. Some excerpts follow:

> Section 6.12 contains the statement: "It shall be the responsibility of the flight crew member to refrain from any activity which might cause him to be fatigued at the commencement of his duty period."
>
> Section 6.12.1.1 states "The flight duty time of a flight crew shall not be scheduled or planned to exceed 15 hours in any 24-hour period."
>
> Section 6.12.2 states "The maximum flight time duty prescribed in 6.12.1.1 may be extended (a) where a pilot-in-command considers that it is safe to do so and a flight is conducted for (iv) the completion of any flight duty that has been extended as a result of unforeseen operational circumstances."

Section 6.12.3 states that the operator will "establish for flight crew members a minimum rest period that allows them to obtain

(a) adequate rest prior to flight duty time, calculated by taking into account the number and type of flight crew member duties that precede and follow the rest period; and

(b) at least one rest period of not less than 24 consecutive hours

(i) once within each seven-day period, or

(ii) 13 times within each calendar quarter."

According to the operator, when the Montreal, Dayton, Montreal flights were planned, with positioning from Ottawa, it was expected that the itinerary could be completed in a flight duty time period of 15 hours. Following this accident, the operator revised the itinerary of the Montreal to Dayton return flights to allow the crews an approximate 12-hour ground stop and a 12-hour flight duty period; this was done by having the crews remain in Montreal during the day.

**1.17.10 Fatigue**

**1.17.10.1 Elements**

Fatigue is a subjective feeling, which has, under controlled scientific conditions, been empirically demonstrated. Elements known to induce fatigue include the following:

Night/day work cycles;
Metergic Dysrhythmia;
Sleep deprivation;
Sleep disturbance;
Long duty days; and
Repeated exposure to the above elements.

The human body has a natural biological tendency to function in cycles or rhythms that, under normal circumstances, follow a 24-hour day/night cycle. Within these rhythms, chemical levels and characteristics within the body change according to specific time frames. For example, bodily temperature will normally fall to its lowest levels at around 0400 hours on any given day. In general, the human body functions best during daylight hours and less efficiently in darkness hours. As a result of this general decrease in efficiency, sleeping during the day and working during the night is more fatiguing than the reverse situation.

Metergic Dysrhythmia is closely related to the problem of night/day cycles, but specifically refers to the biological and performance disturbances often brought on by shift work times. One of the more important considerations related to metergic dysrhythmia involves the effect that shift changes has on circadian rhythms and, therefore, human performance. In general, the body (including the brain) can adapt to changes in time and activity cycles. However, the process of adaptation takes time and varies from one individual to another. One of the common effects of a shift change is an increase in subjective reports of fatigue and an accompanying decrease in productivity. The effects of metergic dysrhythmia are strongest immediately after a shift change and then decrease over time as the body adjusts to the demands of its new cycle.

For the majority of the human population, six to 10 hours of good quality sleep are required each 24-hour cycle. The average number of hours of good quality sleep is approximately eight hours. Some people require more than 10 hours, and a small number of people can exist on as little as five hours. The most common result of not getting adequate sleep is the subjective report of feeling tired or fatigued. Research has clearly demonstrated a cause and effect relationship between sleep deprivation and deteriorated performance.

Five different stages of sleep have been identified. Each stage of sleep is identified by characteristic patterns of brain activity. Stages one to four are progressively deeper stages of sleep. Stages three and four are called Delta sleep. Stage five, called Rapid Eye Movement (REM), is the stage of sleep in which dreaming takes place. While sleep is not totally understood, it has been shown that, to obtain good quality sleep, each individual must progress through the various stages of sleep in some particular pattern or order. These patterns of sleep do vary as a result of a number of issues such as age. A nap (sleep longer than 15 minutes but generally less than two hours) is usually better than no sleep at all, but its regenerative value is extremely limited.

Being awake for long periods is fatiguing. However, the level of fatigue experienced will vary depending on a number of other factors. For example, one factor is the nature and duration of activities undertaken during waking hours. Flying an aircraft is perhaps not the most fatiguing activity one can undertake, but it can lead to fatigue.

Each of the five elements discussed above are empirically known to independently induce fatigue and associated decrements in the efficiency of human performance. However, fatigue is cumulative in nature, and so each of the elements listed will induce a greater degree of fatigue on a collective basis than they will independently. The degree of fatigue experienced and the nature of performance decrements will vary depending on a number of factors, including age, physical condition, and nutrition.

**1.17.10.2 Effects of Fatigue**

Fatigue has been empirically shown to be directly related to a number of specific human performance decrements. Some of these performance effects typically caused by fatigue include the following:

Diminished output;
Increase in performance variability;
Increase in error rate;
Decrease in motor coordination;
Decrease in mental processing capacity;
Increase in response time; and
Decrease in attention span.

# 2.0 ANALYSIS

## 2.1 Introduction

The FDR recording and eyewitness reports clearly show that, from normal cruise flight, the aircraft rolled to the left through approximately 465 degrees. The aircraft essentially conducted a barrel roll, culminating in a steep, high speed, high flight load descent to ground impact. The complete flight upset, from level flight to impact with the ground, lasted 18 seconds.

All major structural portions of the aircraft were accounted for at the accident site. There was no evidence of any of the doors failing in flight or of any other pre-impact structural failure. The FDR recording and engine examination showed that the engines were operating at high power, in a symmetric manner prior to and during the flight upset. The FDR recording and wreckage examination showed that the flaps were in the retracted position throughout the flight upset.

Analysis of the FDR recording showed that, during the upset manoeuvre, the aircraft responded in a way that was consistent with the observed deflection of the primary flight control surfaces. The aircraft did not commence the roll to the left until the left aileron moved up and the right aileron moved down; roll rate was close to that predicted by the manufacturer for the recorded aileron deflection. Pitch attitude changes and flight loads recorded by the FDR were consistent with recorded elevator movement.

There was clear evidence in the form of the captain's comments recorded on the CVR and through examination of the autopilot servo-motors that the autopilot was not engaged, and that the captain was hand-flying the aircraft at the time of the occurrence.

Several factors were examined in an attempt to explain the aileron deflection which precipitated the flight upset, and the maintaining of almost fully deflected ailerons for a period of about 10 seconds.

## 2.2 Initiating Event

### 2.2.1 Pilot Initiated

The ailerons are manually controlled; there are no hydraulic actuators to cause spurious inputs to a flight control surface. The proper up and down relative response of the ailerons indicates that the ailerons initially moved from their level flight cruise position because of movement of the cables connected to the cockpit control wheels.

The FDR recorded a small rolling motion to the right followed by slight wheel-left aileron movement. The aircraft roll direction was stopped then reversed quickly, rolling to the left as the rate of aileron deflection increased sharply. The rapid increase in the rate of aileron deflection occurred about one second after a comment by the captain that he saw a small airfield.

### 2.2.2 Incapacitation

It was clear from the CVR that the first officer was conscious and aware during the accident manoeuvre. In the case of the captain, the last definite recorded CVR comment ("there's another little grass strip there") was spoken about one second before the ailerons began their high rate of deflection.

The CVR recording reveals that the pilots were selecting "intercom" on their control wheels when they wished to speak. In addition, the cockpit area microphone was not picking up normal conversation being conducted by intercom; it was being drowned out by engine sounds. The fact that nothing was recorded from the captain's microphone or the cockpit area microphone does not mean that the captain was not talking or not capable of talking. The intercom selector switch was left OFF and, hence, nothing was recorded. The intercom switch, which is located on the left portion of the captain's control wheel, would have been down when the control wheel was hard-over to the left; the switch would have been harder than normal to select.

Just before impact, an unintelligible utterance was recorded faintly by the CVR, on both the first officer's intercom channel and the cockpit area microphone. Analysis of CVR sounds showed that the first officer left his intercom switch selected ON after his last "speed" warning to the captain. The fact that the sound was able to be recorded on the cockpit microphone channel means that it was louder than normal speech. The fact that the unintelligible

utterance is heard faintly on the first officer's intercom channel means that the first officer did not make the sound. Had he done so, the sound would have recorded clearly. Because it was recorded on the cockpit area microphone, the sound had to be louder than normal speech. The conclusion reached is that the captain made the sound of the utterance, and thus, he was conscious during the manoeuvre.

Supporting this conclusion were the control forces required from the captain during the manoeuvre. It was estimated that elevator control forces (wheel back) exceeded 100 pounds for about 10 seconds of the manoeuvre. The CVR shows that the first officer had a passive role during most, if not all, of the manoeuvre; he was providing warnings to the captain, indicating that the captain was doing the flying. Based on the direction and magnitude of the required control-wheel force, it is clear that the captain had not become incapacitated and slumped over the control wheel.

### 2.2.3 Intentional Roll

The possibility that the captain intended to perform an aerobatic roll was considered. This possibility was considered to be extremely unlikely. Such an action would have been totally out of character for the captain, who was known to be a cautious, conservative person with a stated aversion to the sensations of aerobatic flight. In addition, there is no mention on the CVR of an intent to perform a roll, which likely would have been the case for such a show-off type manoeuvre.

### 2.2.4 Aircraft Avoidance

No eyewitness saw another aircraft near the accident flight at the time of the roll manoeuvre. Radar tapes and observations showed that there was no other traffic near C-GFFA at the time of the accident. No comment was recorded on the CVR discussing other traffic. There is no indication that aircraft avoidance was the reason for the application of aileron by the captain.

### 2.2.5 Observation of Ground Feature

Study of the area where the upset occurred shows that a newly constructed airfield would have been visible to the captain off his left side but would have been slightly behind him. This airstrip was the only one found to be visible near the location of the roll manoeuvre. Shortly after the captain noticed the airstrip, his view of it would have been obstructed by the left wing. The interest shown by the crew in observing local geographical features and airstrips,

recorded by the CVR during the previous minutes of the flight, leads to a conclusion that the captain applied control-wheel force to bank the aircraft to the left. In doing so, he would have been able to view the airfield that interested him. The location of the ground feature and the speed of the aircraft would have allowed limited viewing time.

The practice of changing an aircraft's roll attitude to better observe a ground feature is not an unusual pilot action, when conditions permit. Because the flight carried no passengers or cargo, the captain was not inhibited from putting on more than normal angles of bank or applying aileron at a higher rate than would be allowed for passenger comfort. The limited time for viewing would be an inducement to roll the aircraft quickly. Also, the fact that left-wing-down aileron was already being applied, to correct the small rolling tendency to the right, would have required greater than normal left-wing-down wheel force to achieve the objective of rolling the aircraft left to observe the airfield. The reason for the slight roll to the right is not known, although local turbulence could have been the reason. Occasional mechanical turbulence was forecast during gusty wind conditions; gusty winds were present at Ottawa Airport near the time of the accident.

Thus, it was concluded that the initiating event for the accident manoeuvre was control-wheel force to the left, applied by the captain to allow him to view an airfield to the left of the aircraft. The control force applied was higher than normal likely because of the limited observation time, an existing left-wing-down control force to counter a slight right rolling tendency, and the absence of passengers or cargo.

## 2.3 Aileron Performance

### 2.3.1 Aileron Response

The response of the aileron system to a control input by the pilot depends on several factors, including the following: system design, rigging, and system malfunctions. These factors will determine the forces required and produced by the system and will result in the control effect desired by the pilot, if the system is working correctly. Clearly, the aircraft response to the captain's left-wing-down control input was unexpected. Within 1.5 seconds of control-wheel input, both ailerons were fully deflected with the right aileron at an angle about 2.3 degrees greater than the ground calibration deflection; the left aileron had 1.2

degrees more deflection than the ground calibration deflection value. The aircraft responded with a roll to the left at about 46 degrees per second. Examination and analysis of the aileron system indicated that the ailerons deflected fully and remained almost fully deflected until just before ground contact, as a result of aileron aerodynamic overbalance. Post-impact measurements of the aileron system, FDR information, and flight tests indicated that this overbalance occurred because of asymmetrically rigged ailerons.

### 2.3.2 Normal Aileron System

The HS 748-2B aileron system is designed with ailerons rigged up 1.5 degrees from the chord line. At 200 KIAS, the expected control wheel peak force for aileron deflection is 48 pounds at slightly more than one-half control-wheel travel (11.5 degrees of aileron travel). The wheel force will lighten to less than one-half the peak force at full deflection. However, full control deflection is not allowed at 200 KIAS because $V_A$ is 155 KIAS.

The unstable force gradient of each aileron, caused by the design of aerodynamic balance required for reasonable forces at low control surface deflections, requires careful rigging. This rigging is designed to ensure that the ailerons interact in such a way that a negative wheel force or overbalance does not occur. A spring system supplying approximately 17 pounds of aileron control force at maximum wheel deflection is designed to reduce the chance of aileron overbalance. Rigging the ailerons up does reduce the peak wheel force and causes that force to occur at a lower wheel angle.

### 2.3.3 Evidence of Asymmetric Aileron Rigging

#### 2.3.3.1 Post-Impact Measurements

The mechanical assemblies that moved the ailerons were measured by noting the number of screw threads on adjustable fittings. The control rod thread count measurements found on the accident aircraft were outside of the range of counts for all nine sample aircraft, two aircraft at the manufacturer's plant (rigged normally, 1.5 degrees up from the chord line), and from the values provided by the operator for seven of its aircraft (aircraft which had passed the NTO No. 5 handling test). Relative rigging was calculated with one thread count equal to 0.75 degrees of aileron change.

The difference between the sample aircraft at the minimum control rod thread count range (down-rigging) compared to the accident aircraft was 2.5 threads less (5.5 threads versus 3.0 threads for the accident aircraft right aileron rod). This indicates a difference of rigging of 1.9 below the rest of the sample aircraft.

The maximum control rod count difference (up-rigging) of the accident aircraft to the sample aircraft was 3.5 threads more (11.5 threads versus 15 threads for the accident aircraft left aileron control rod). This would indicate upward rigging of the left aileron 2.6 degrees from normal.

The average of the thread counts, excluding the accident aircraft, was approximately 8.5 threads. Comparing the measured values of the accident aircraft to this average value gives a thread difference of 6.5 (15 - 8.5) for the left aileron or an indication of up-rigging of approximately slightly less than 5 degrees above a normal aircraft. Comparison of the measured right aileron thread count yields an indication of right aileron down-rigging of approximately 4 degrees from normal rigging.

The final rigging estimate would depend upon the proportion of difference in the clevis end adjustment of the control rod assemblies assigned to the left and right aileron. The difference of 0.21 inches in the clevis length equates to 2.6 degrees of adjustment.

Because of the tolerances in the manufacture of the sample aircraft and the accident aircraft aileron systems and because of the adjustments that can be made in the system, it is not possible to determine the exact rigging based solely on the accident aircraft's operating rod thread measurements. However, it is clear that the accident aircraft had operating rod adjustments significantly beyond those of the nine nominally rigged aircraft samples (two at the manufacturer's plant and seven aircraft belonging to the operator). The differences in adjustment clearly show that the left aileron was rigged higher than 1.5 degrees, and that the right was rigged lower than 1.5 degrees.

### 2.3.3.2 Left Aileron Float Down

The FDR recorded an approximate 3.5 degrees float down with increasing airspeed, from the gust-lock control neutral position of the left aileron. The change in the right aileron neutral point with airspeed increase was negligible. The manufacturer gave an opinion that

this could represent an asymmetric situation with the left aileron rigged higher by approximately the float down angle.

The fuel imbalance, likely present, might have accounted for part of the FDR measured downward motion of the left aileron, but would have been responsible for less than 0.5 degrees of travel.

The test flight of the sister aircraft, C-GBFA, confirmed that the higher rigged aileron did float down further than the lower rigged aileron. The test aircraft had the right aileron rigged 0.6 degrees higher than the left aileron (1.4 degrees versus 0.8 degrees); both ailerons were rigged above the chord line. The right aileron floated down about 1.8 degrees, and the left aileron moved down 1.0 degrees. The final position for the ailerons in cruise was minus 0.4 degrees (down) for the right and minus 0.2 degrees (down) for the left, relative to the chord line. These values are in the range of normal cruise aileron float-down position predicted by the manufacturer (-0.1 to -0.7 degrees down).

The test aircraft had the control wheel cocked to the left during trimmed flight. This is consistent with the prediction of the manufacturer that the wheel would be cocked toward the low-rigged aileron. In the case of the test aircraft, both ailerons moved down, not just the high-rigged aileron. The initial rigged point can account for the difference. The test aircraft had both ailerons rigged above the normal cruise float-down position, and they tended to move toward that position.

In the case of the accident aircraft, the fact that only the left aileron moved shows that the right aileron was already rigged close to the normal cruise aileron float-down position. The left aileron float-down of approximately 3.5 degrees is strong evidence of asymmetric rigging with the left aileron high. The observed FDR performance, coupled with the indications of asymmetric rigging produced by the control adjustment measurements, leads to the conclusion that the left aileron rigged position was at least 3.0 degrees up from the chord line and the right aileron rigged position was slightly below the chord line.

The FDR recording of aileron performance and the rod thread measurements are consistent evidence of asymmetric aileron rigging, with the left aileron rigged higher than the right.

### 2.3.3.3 Substituted Aileron

The left aileron on the accident aircraft was the factory-installed aileron from another of the operator's HS 748, C-GBFA. The aileron was inadvertently installed on the accident aircraft by a U.S. maintenance contractor and, once installed, the operator decided to leave it on the aircraft. C-GBFA now had the original factory-installed left aileron from the accident aircraft.

Because the sister ship had its ailerons rigged lower than the minimum of 1.5 degrees above the chord line, it would be expected to pass the NTO No. 5 test more readily than a correctly rigged aircraft. However, the aileron rigging of C-GBFA did not provide the proper flight loads to the wing, when the aircraft was operated at maximum zero fuel weight.

The records of both aircraft showed that each aircraft left the manufacturer with different adjustments made to the balance tabs of their left ailerons. The original aileron in place on the accident aircraft had its balance tab control rod "screwed in 1 and 1/2 turns." The original left aileron from C-GBFA had the same tab control rod screwed in 2 and 1/2 turns, when it left the manufacturer.

According to the HS 748 Maintenance Manual, inward turns of the tab rod adjustment reduce aileron control forces. The tab to aileron surface lagging angle increases and the tab-generated balancing force is increased. Therefore, the substituted aileron, with one more inward turn of the tab rod adjustment, would have given lighter control forces to the accident aircraft when left wheel was applied.

### 2.3.3.4 Aileron Control Cable Tension

The fuselage cable loop tension regulator is designed to maintain constant tension for a variety of temperature and pressure induced conditions. Although the pre-impact tension of the loop could not be determined, there is no indication of a fault with the regulator.

The right wing cable loop had turnbuckle measurements close to nominal; whereas, the left wing cable loop turnbuckle measurement was 0.27 inches longer than on other HS 748. This increased turnbuckle length could indicate lower than normal cable tension in the left wing cable loop. Manufacturing variances in the cable lengths could account for some of the differences in the turnbuckle measurement and, thus, make it

impossible to make a definite conclusion based solely on turnbuckle measurements.

The FDR does show evidence of possible low cable tension in the left wing loop. During the roll manoeuvre, at RT 1228 to RT 1229, the right aileron deflection decreases by 3.0 to 4.0 degrees. At the same time, there is only a 0.5 to 1.0 degree reduction in left aileron deflection. This behaviour can be accounted for by loose cable tension in the left loop which would not allow sufficient force on the mechanism to move the left aileron. The decreasing deflection of the right aileron is evidence of efforts to move the ailerons back toward neutral.

The operator had to conduct several flights on one aircraft in order to pass the NTO No. 5 airtest. This aircraft was later shown to have low tension in the wing loop aileron control cables. Following tensioning and a small control rod adjustment, the aircraft was able to pass the test. This indicates that the wing loop cable tension does have an effect on the overbalance tendency of the aileron system. The aileron system requires proper force balance between the two ailerons, which in turn depends on proper cable tension.

There was no record found regarding tensioning of the aileron loops or checking the cable tension while the accident aircraft was in the possession of the operator. Low cable tension, if present, would have been undetected.

**2.3.3.5 Aileron Maintenance/Repairs**

During May 1988 maintenance by the U.S. contractor, repairs were made to the right aileron of the accident aircraft. On 30 August 1988, it was reported that the right aileron attachment bracket had suffered compression damage possibly because of wind or jet blast. This component, which attaches the aileron to the adjustable control rod, was replaced. Any differences in size or hole spacing between the two brackets would cause differences in aileron rigged position. This could have altered the rigging of the right aileron.

Maintenance records from the U.S. contractor show aileron position measurements taken of the trailing edge of the ailerons, relative to the wing trailing edge at the time that the original ailerons were removed. A measurement for the "left aileron" was 28/64 inches up. The "right aileron" measurement recorded was 28/32 inches. With 0.75 degrees equal to

0.19 inches of measurement, it would seem that the right aileron was rigged up 3.45 degrees above the chord line and the left aileron was rigged lower at 1.72 degrees up from the chord line, prior to aileron removal. In light of other strong physical evidence of a higher rigged left aileron (left aileron down-float and control rod measurements), it is concluded that the locations of the measured ailerons were likely recorded incorrectly. The measurements do provide further evidence that aileron rigging asymmetry did exist on the accident aircraft.

### 2.3.4 Airtests

The maintenance work carried out on the ailerons of the accident aircraft required an NTO No. 5 type airtest to verify aileron performance. The left aileron had been replaced, and the right aileron had been repaired to a degree that rigging and characteristics would have easily changed. No airtests were conducted to ensure that aileron control forces were normal, and that aerodynamic overbalance or "lock" would not occur.

From discussions with other operators, it is apparent that confusion exists as to when the airtest is required. Three different action phrases "should", "required", and "must" mean different things to different readers. Also, the reason for the airtest and its importance were not known to many operators, including Bradley Air Services. Prior to the accident, most pilots were not even aware that aileron overbalance could occur on the HS 748.

The results of the airtests following the accident clearly show the value of the aileron handling airtest. Aircraft were flying with ailerons rigged in a manner that would allow aileron overbalance. A pilot employed by the operator had previously experienced aileron overbalance. This would likely have been avoided if the airtest had been conducted.

The experience of the operator shows that the aileron response of an aircraft that has successfully passed the NTO No. 5 test can change during normal service to a point where the ailerons will overbalance. The manufacturer has indicated that perhaps the rate of aileron application during the NTO No. 5 airtest may provide an apparent successful result, but the aileron may still display an overbalance tendency. Thus, the aircraft tendency for aileron overbalance may not change with service but may be an indication of inconsistent testing. However, the NTO No. 5 and Maintenance Manual do not address the rate of aileron application near the aileron stop as an important testing variable.

One disturbing aspect of the aileron overbalance potential of the HS 748 is that it can apparently escape detection by the NTO No. 5 test. The aircraft may just pass the aileron handling test at 155 KIAS, but at 200 KIAS aileron overbalance could still occur, according to the manufacturer. This is because of the inability of the centring spring to overcome the larger aerodynamic forces at the higher speed.

### 2.3.5 Aileron Overbalance

#### 2.3.5.1 Force Gradient Effects

From hinge-moment data, it was seen that control-wheel force is determined by the net balance of the aileron system, which is a function of the neutral position of the ailerons. If they are both rigged up from the wing chord line, aileron control-wheel forces lighten; the deflection angle, at which the peak force is encountered, is lowered. Although acceptable to certification standards, provided there is no negative or aerodynamic overbalance force, such peaking, then falling off, in control-wheel force with increased deflection is an undesirable control characteristic; it makes inadvertent over-control easier.

#### 2.3.5.2 Influence of Aileron System Asymmetrical Rigging

With too much symmetric up-rigging, that is, with an aileron system neutral point too high above the wing chord line, the aileron control forces will become too light. If the pilot deflects the control wheel outside of a rather modest central range of aileron angles, he may, because of the abrupt fall-off in control-wheel force, apply more aileron than he intends. Although there is a spring system that comes into play at half wheel and applies a progressively increasing force to reach about 17 pounds at 88 degrees of wheel travel, it is possible to misrig the ailerons so that this design feature is not adequate.

If the ailerons are asymmetrically rigged, then it is possible to get into the region where the aileron control force drops dramatically before the aileron return springs can come into play. In effect, the aircraft is biased to roll more readily in one direction than the other. Because of the location of the control stops and their designed limits, an aileron can be rigged high enough to render the stops ineffective in preventing an overbalance position. This appears not to comply with the intent of FAR 25.675. A negative or overbalance force is developed toward the end of the wheel travel; the ailerons apply themselves. The result can be a hard-over wheel force

that the surprised pilot must be prepared to resist or overcome. This is what was experienced by the crew of the operator's aircraft that rolled 90 degrees before control was regained.

The fact that the roll rate was higher during the accident manoeuvre than for a HS 748 with full aileron deflection is further evidence that the ailerons were deflected to a greater angle than was normally possible. It is concluded that the ailerons were being held against the stops by aerodynamic overbalance forces. The normal deflection change of 18.5 was exceeded by 2.3 degrees, for the right aileron, during the accident manoeuvre.

There is strong evidence (aileron float down and aileron control rod measurements) that asymmetric rigging of sufficient magnitude to cause aileron overbalance was present. The physical evidence leads to a conclusion of aileron rigging asymmetry of at least 3.4 degrees, with the left aileron at 3.0 degrees up and the right aileron slightly below the chord line. Calculations, based on aileron hinge-moment curves provided by the manufacturer, show that a overbalance force of about 37 pounds is present with this asymmetrically rigged condition. Greater asymmetry would lead to a larger aerodynamic overbalance force holding the aileron system deflected.

## 2.4 Crew Reaction

### 2.4.1 Observed Reactions

Once the captain had applied the wheel force to bank the aircraft to the left and had applied sufficient force to move the wheel past the point of peak force (approximately half wheel travel), control-wheel forces would have decreased quickly from a maximum wheel force of 51 pounds occurring at approximately at half-travel. Before the end of the normal wheel travel, force would have been applied by the aileron system in such a manner as to move the controls to full deflection. The ailerons would drive the control wheel to full deflection. The captain then had to apply a wheel force to return the wheel to neutral, plus any further wheel force to restore the aircraft to level flight.

The magnitude of the forces holding the ailerons against the control stops was calculated to be about 37 pounds. This calculation is based on conclusions that are not absolute. For example, larger aileron deflection angles than indicated by the FDR (which is possible) would increase the force. If the left wing

aileron control loop tension was low, then the aileron system forces between the left and right aileron would be altered, possibly requiring greater force input by the captain. Aileron system friction would add some force to be overcome in returning the ailerons toward neutral. Based on all the evidence, it is concluded that the captain had to deal with an initial aileron overbalance force of at least 37 pounds.

The FDR shows that the ailerons stayed nearly fully deflected for about 10 seconds. There is no indication of what opposite control-wheel force was applied by the captain, or exactly when it was applied. Undoubtedly, the captain applied some force when he intended to stop the roll. Assuming that he did not intend to exceed 45 degrees of bank, the maximum time until this opposite wheel would have been applied by the captain was about 2.5 seconds after the rapid control input, or 1.0 seconds after the maximum aileron deflection was established. The right aileron does show a very slight lessening of its deflection within a second of its full deflection. This likely indicates some effort to turn the wheel to right. The fact that the left aileron deflection did not lessen shows that the system overbalance force was greater than the opposite wheel force the captain applied. Although there are indications that the captain made some attempts to return the ailerons to neutral shortly after they were fully extended, there is no indication of coordinated crew effort to deal with control problem.

The table from "Aircraft Stability and Control for Pilots and Engineers" gives a value for the "maximum comfortable force for a short time" as 30 pounds and the "maximum permissible force for a short time" of 50 pounds. The minimum wheel force the captain had to overcome was 37 pounds; the force was likely greater. As the upset manoeuvre progressed, the control-wheel force required to restore the ailerons to neutral increased to greater than 68 pounds. The forces the captain had to apply exceeded the maximum permissible textbook values and the maximum one-handed force given by FARs. To the captain, this amount of negative wheel force would have probably appeared to be an aileron control jam.

When the aircraft was nearly inverted, the captain applied wheel back pressure which caused an elevator deflection of about three degrees. This control action caused the aircraft to change from a simple roll to a barrel roll manoeuvre. The elevator deflection, happening where it did in the manoeuvre, quickly created a critical recovery situation. The rate of descent increased quickly and, from such a low

altitude, only a few seconds were available for any recovery action attempts.

There were likely several reasons why the inappropriate back force was applied when it was. It was known that the captain did not enjoy the sensation of negative g; he may have applied the force subconsciously to maintain positive g. It is possible that the captain did not have his shoulder harness fastened, which could have induced him to apply elevator to keep him in his seat. From the simulator tests conducted at Hatfield, it was observed that the VSI first showed a descent at about the same point in the manoeuvre as the wheel back force was applied. The pilot may have reacted to an observed descent with the method he had always used, back pressure on the control wheel.

As the manoeuvre progressed, there were strong indications that efforts were being made to restore the ailerons back from their locked condition. The right aileron deflection reduces and the left aileron shows some smaller amount of reduction. Unfortunately, as the aircraft speed was increasing rapidly, the aileron overbalance force was also increasing. At 250 KIAS, the force was likely in excess of 68 pounds. By this time, several physiological factors would have been affecting the pilot's ability to recover from the manoeuvre.

The roll rate during the manoeuvre was in the range of that of a jet aerobatic trainer. To the uninitiated, such a roll can be confusing and can lead to disorientation. The g forces developed in the last seconds of the flight were large enough to cause many pilots to at least "grey-out." Pilots unaccustomed to such g levels would normally be the most affected. The combination of control forces being applied by the pilot (100 to 150 pounds back pressure, plus the aileron force) would have taxed a pilot's strength. Despite all this, the ailerons did return to neutral before impact.

It is not known whether the captain was able to force the ailerons back to neutral or whether the first officer provided assistance at this time without being asked. However, by the time the aileron aerodynamic overbalance was removed, the aircraft was descending rapidly with a 30-degree down attitude and had approximately 90 degrees of bank. Recovery, with only three seconds remaining to impact, was impossible.

### 2.4.2 Training/Experience

Recovery from the emergency faced by the crew was likely possible, but required very rapid positive action. Neither pilot was trained in aerobatics and, likely, the rapid roll caused them anxiety and confusion. At certain points of the manoeuvre, the captain was faced with unusual situations for which he had never been trained. For example, should he roll the aircraft through after a certain point, and what was that point? Aerobatic training should not have been a requirement when flying this type of transport-category aircraft.

The emergency procedures, which the crew learned by memory for quick use, did not include recovery from a aerodynamically overbalanced aileron. Neither the Flight Manual nor the Crew Manual indicated that aileron overbalance was a possibility. The existence of aileron overbalance is implied in the Maintenance Manual and NTO No. 5, in that failure of the flight test ("the ailerons remain at full travel upon release") can be recognized as an example of aileron overbalance. It is unlikely that the crew had seen either document, because the operator had not distributed NTO No. 5 to its crews and the Maintenance Manual is not normally a flight crew document. The fact that the crew who conducted the flight test on C-GFFA did not carry out the required aileron flight test following the extensive maintenance in the U.S., and the fact that they were not even aware of the existence of the aileron flight test is further evidence that regular line crews were not aware of the possibility of aileron overbalance. The absence of informing documents led to a lack of knowledge, which caused a delay in reaction time. Had the crew been aware of the possibility of the aileron overbalance phenomenon, they might have been able to come up with a quick two crew member response. No time would have been lost in trying to sort out an unknown problem.

### 2.4.3 Fatigue

Review of the crew's schedule for the three days prior to the accident reveals several elements which could have led to fatigue.

First, the crew was exposed to night/day work cycles, and they had just started what was fundamentally a night shift type schedule. The work day or flight duty time was approximately 16 hours for each of the two previous days. At the time of the accident, the crew had been on duty for 16 hours. The time available for sleep between each arrival and departure was very limited. The captain was obtaining less than four

hours of sleep during the day and perhaps was able to have a short, disturbed sleep for an hour during the ground stop at Dayton. All these elements, particularly when repeated, have been identified as factors that cause fatigue. There is no reason to expect that these pilots would not have been affected to some extent by fatigue at the time the flight control problem occurred.

The known effects of fatigue such as increased response time and decreased mental processing capacity may have made reaction to an unknown or untrained-for event slower than normal. Diminished output and decrease in motor coordination may have reduced the chance of recovery from the roll manoeuvre.

From the number of the Montreal to Dayton flights that caused the 15-hour flight duty time limit to be exceeded, usually by almost exactly one hour, it can be concluded that the operator's scheduled or planned flight duty time expectation was not realistic. The flights as planned and flown did not conform to the operator's Operations Manual regarding flight and duty times and, therefore, exceeded the duty times for safe flight as established by the regulatory authority in ANO Series VII, No. 2.

## 3.0 CONCLUSIONS

### 3.1 Findings

1. The design of the HS 748 manually operated ailerons requires very precise rigging to avoid aerodynamic overbalancing.

2. The importance of the precise rigging requirements and the compliance requirements of a post-maintenance aileron airtest were not known by the operator and other operators.

3. The left aileron of the accident aircraft was inadvertently replaced by the left aileron from C-GBFA by a U.S. maintenance contractor.

4. The operator decided to leave the substituted aileron in place on C-GFFA.

5. Following the U.S. contractor maintenance, the flight test conducted by the operator did not test aileron control response in accordance with instructions contained in the HS 748 Maintenance Manual or with directions in the BAe NTO No. 5.

6. Following repairs to the right aileron, no test flight was conducted.

7. The ailerons were asymmetrically rigged; the left aileron was rigged higher than the right.

8. The substituted left aileron likely had a different tab adjustment than the original aileron which would have produced lower aileron system forces for a left roll.

9. There is evidence to suggest that the left aileron control cable loop had less than normal tension, but this could not be confirmed.

10. The tendency for aileron overbalance may exist despite successful completion of the NTO No. 5 handling airtest, either because of change of system response and performance during normal service use, or because of inconsistent aileron application rates during the airtest.

11. The pilot of the accident aircraft applied a large control-wheel deflection to bank the aircraft to the left, probably to observe a ground feature.

12. The aileron system asymmetric rigging allowed the ailerons to aerodynamically overbalance (lock) when the large control deflection was applied.

13. The control-wheel force required to restore the ailerons toward neutral, during the upset, likely exceeded the defined "maximum permissible force for a short time, using one hand."

14. The back elevator control input by the pilot, during the inverted portion of the aircraft roll, increased the descent rate.

15. The control-wheel force required in the latter portion of the manoeuvre was near the defined "maximum permissible force for a short time, using two hands."

16. The elevator forces applied by the pilot during the manoeuvre exceeded the defined "maximum permissible force for a short time, using two hands."

17. The crew's reaction to aerodynamically overbalanced aileron controls was likely degraded by a lack of information regarding the possibility of aileron overbalance on the HS 748.

18. Neither pilot had received any aerobatic training; nor should such training have been required for the category of aircraft being flown.

19. There was evidence that factors which could lead to the development of flight crew fatigue were present; the flight crew's reaction to the control problem would probably have been degraded by fatigue.

20. The crew's attempts to recover from the upset would have been degraded by physiological forces induced by the manoeuvre.

21. There was likely no deliberate attempt by the captain to perform an aerobatic roll.

22. The flight upset was not induced by pilot incapacitation.

23. The HS 748 Maintenance Manual instructions to correct aileron overbalance, following flight test, do not direct the user to verify or adjust other portions of the aileron system, such as control cable tension.

24. The design of the HS 748 aileron control stops allows adjustment of the ailerons to a position where adverse performance can be encountered.

25. The aileron control system cable tension had not been inspected because the 4,000-hour inspection cycle requiring such checks had not yet been reached while the aircraft was possessed by the operator.

26. It is not normal practice for Transport Canada to review Letters-to-Operators, including NTOs, unless specifically requested to do so by an operator.

27. The compliance requirements of NTOs are not certain.

28. The crew duty time exceeded the allowable time provisions of ANO Series VII, No. 2.

29. The flight crew were certified and qualified for the flight in accordance with existing regulations.

30. The weight and centre of gravity were within the prescribed limits.

## 3.2 Causes

The Board determined that the aileron control system was asymmetrically rigged, making it susceptible to aerodynamic overbalance. The operator did not conduct the required post-maintenance flight tests of the aileron control response. When the ailerons were held at full deflection by aerodynamic forces, following a large control-wheel input by the pilot, the subsequent control reaction by the pilot was inappropriate.

Contributing to the accident were the design of the aileron system; ambiguous and incomplete maintenance instructions; a lack of published information for flight crew concerning aileron system performance and possible emergencies; and the presence of factors which may have led to the development of flight crew fatigue.

## 4.0 SAFETY ACTION

### 4.1 Action Taken

#### 4.1.1 Flight Scheduling and Crew Duty Times

The schedule for the Montreal/Dayton flights did not enable the flight crew to comply with the duty time limitations of Aeronautical Navigation Orders (ANO) Series VII, No. 2, and exposed them to a number of conditions known to be conducive to fatigue. Insufficient sleep over the preceding three-day period (a total of 12.5 hours for the captain and 17.5 hours for the first officer), long duty periods (16 hours per day), poor conditions for sleep (napping in the aircraft between flights), reversal of the normal cycle of working during the day while sleeping at night, and the need to adapt to this reversal of work cycles every three days, all would have tended to impair human performance. Because these factors are cumulative in nature, their total effect would have been greater taken together than if each had occurred separately.

Fatigue may adversely affect performance by increasing response times and impairing both motor coordination and mental processing capabilities. The fatiguing work conditions then could have slowed the crew's reaction to an unfamiliar event and reduced the chance of recovery from the uncommanded roll manoeuvre.

After the accident, the operator eliminated the ferry flights between Ottawa and Montreal by allowing the crews to stay overnight in Montreal. This change reduced the daily flight duty times by approximately two hours, putting them within the duty time limitations specified in the Regulations for safety purposes.

#### 4.1.2 Aileron Rigging

During the initial phase of the investigation, it was found that incorrect rigging of the aileron control system on the HS 748 could result in aileron aerodynamic overbalance, a condition whereby aerodynamic forces move the ailerons to, and hold them in, a fully deflected position. Because of the possibility that this condition could be encountered on other HS 748 aircraft, the Canadian Aviation Safety Board (CASB), the predecessor to the Transportation Safety Board of Canada (TSB), issued an Aviation Safety Advisory to Transport Canada (TC) on 23 September 1988.

This Advisory suggested that TC confirm that the aileron systems on all Canadian-registered HS 748 aircraft were rigged in accordance with manufacturer's specifications, and that the aileron control forces were normal. The Adviscry also suggested that TC reassess the requirements for flight testing following any maintenance on the aileron control system.

After contacting the manufacturer and all operators of the HS 748, TC issued a Service Difficulty Advisory (SDA) on 08 December 1988. It encouraged all Canadian operators of HS 748 aircraft to follow rigorously and completely the instructions contained in both the Maintenance Manual and in Notice to Operators (NTO) No. 5 regarding the rigging and flight testing of this aircraft's aileron system. The Advisory also cautioned operators that failure to accomplish the flight test and the subsequent adjustments could result in the ailerons remaining in the fully deflected position.

Subsequently, all 29 Canadian-registered HS 748 aircraft were flight tested, and four aircraft were found to require adjustments to their aileron rigging before they were able to pass the flight test.

Also, shortly after the accident, the aircraft manufacturer telexed all operators of the HS 748. In the telex, the manufacturer informed operators of the accident and stressed the need for all engineering and operational staffs, particularly flight crews, to be fully conversant with the contents of all NTOs issued by British Aerospace (BAe) for the HS 748. The telex also informed operators that they are required to carry out an aileron handling flight test, in accordance with NTO No. 5, following certain maintenance actions specified in chapter 27-10-0 of the HS 748 Maintenance Manual.

## 4.2 Action Required

### 4.2.1 Aileron Overbalance

The aileron system used on the HS 748 is more susceptible to overbalance than other designs currently used on aircraft of similar size and speed. However, this aircraft can be operated quite safely if the ailerons are properly rigged and maintained, and if flight crews are adequately prepared for the possibility of aileron overbalance. Thus, the Board's recommendations are focused on these aspects rather than on a change in design.

Prior to the accident, many HS 748 operators were not aware of the requirement to conduct an aileron handling flight test whenever an aileron or tab was changed or repaired. This was confirmed by the results of a survey which was conducted by TC. The survey revealed that four HS 748 operators, with a total of 19 aircraft, had not flight tested their aircraft because they had interpreted the Maintenance Manual test as being optional.

Potential for misinterpretation of the aileron handling flight test requirement still exists. The section of the HS 748 Maintenance Manual which describes the aileron handling flight test, as amended 30 September 1984, states, in part, "When an aileron is changed or repaired, or if the aileron or tab rigging has been adjusted for any reason, then a flight test should be carried out as detailed below." To some, use of the word "should" in this sentence suggests that, although the flight test is recommended, it was not obligatory. Furthermore, this wording is in contrast to that used in revision No. 1 of NTO. No. 5, dated 01 March 1984, where the word "must" was used in reference to the test requirement. Although a subsequent sentence states "The aileron handling must be checked in flight as follows", this statement pertains only to how the airtest is to be done, not that one is required.

Although operators were notified of the requirement for the flight test by telex from BAe and by an SDA from TC, the Maintenance Manual, which is the aircraft maintenance engineer's (AME) primary reference document, remains unchanged.

The Board is concerned that the importance of conducting the flight test, as indicated in interim reminders such as NTOs, SDAs, and telexes, could be overlooked unless the source document is amended. Therefore, the TSB recommends that:

> The Department of Transport ensure that the HS 748 Maintenance Manual is amended to state that flight testing of the aircraft's aileron system is mandatory following the rigging, repair or replacement of an aileron or tab.

(A91-16)

Also prior to the accident, many HS 748 operators were not aware of the importance of ensuring that all portions of the aileron system were properly adjusted before conducting the flight test. The Maintenance Manual states "The ailerons should be installed in accordance with Chapter 27-10-0, Page Block 401 and the rigging completed as per the foregoing instructions." The word "should" is used again, which may suggest to some that there is no obligation to ensure that the installation and rigging of the ailerons are correct before conducting the flight test. This creates a potentially hazardous situation because, if certain portions of the aileron control system, such as control cable tensions or control stops, are not properly adjusted before a test flight, any aerodynamic overbalance condition that might be encountered during the test flight could be exacerbated.

Therefore, the TSB recommends that:

> The Department of Transport ensure that any necessary changes are made in the HS 748 Maintenance Manual procedures so as to minimize the probability of aileron overbalance; and
>
> (A91-17)
>
> The Department of Transport require that, before any aileron handling flight test is conducted, all portions of the aileron system be installed and rigged in accordance with applicable sections of the Maintenance Manual.
>
> (A91-18)

The control-wheel force required to restore the ailerons toward neutral during the first portion of the flight upset should have been within the capability of either crew member. Indeed, the crew did neutralize the ailerons just before impact when the force required would have been at a maximum. Even though large control-wheel forces might not be required to recover from an overbalance situation, unexpectedly experiencing such handling characteristics is potentially dangerous. Had the flight crew of the accident aircraft been aware of the potential for aileron aerodynamic overbalance and of the recovery action required, they might have been better prepared to neutralize the ailerons before the aircraft entered an unusual attitude.

NTO No. 5 had cautioned that, if the ailerons were not rigged properly, they might remain at full travel and assistance from the pilot would be required to recentre the control wheel. Although the NTO had stated that its contents should be brought to the attention of all HS 748 pilots, an amendment to the flight manual and crew manual would have been a more effective means of communicating this information to pilots because these are the documents that pilots rely upon for aircraft handling information.

Although this accident has sensitized the HS 748 community to the potential for aileron aerodynamic overbalance, to ensure a continuing awareness, and to better prepare pilots, the TSB recommends that:

> The Department of Transport ensure that the HS 748 Flight Manual and Crew Manual are amended to include appropriate warnings regarding the possibility of aileron aerodynamic overbalance and procedures to be followed should it be encountered.
>
> (A91-19)

### 4.2.2 Manufacturer's Recommendations - Letters-to-Operators

The country of manufacture of an aircraft is obligated by section 4.2 of annex 8 of the International Civil Aviation Organization (ICAO) Standards to transmit to contracting states any generally applicable information which it has found necessary for the continuing airworthiness of an aircraft and for the safe operation of an aircraft. To further ensure the continuing airworthiness of Canadian-registered aircraft, TC routinely reviews all manufacturer's service bulletins and, if required, issues Airworthiness Directives (ADs). TC's review of service bulletins is in accordance with paragraph 5 (b) of section 571.101/4 of the Airworthiness Manual Advisory (AMA), which states that manufacturer's recommendations, such as service bulletins (which primarily concern aircraft maintenance) and Letters-to-Operators (which primarily concern aircraft operation) are assessed by TC to determine their acceptability.

Although all service bulletins are reviewed by TC, Letters-to-Operators, including NTOs, are usually reviewed by TC only if a specific request to do so is received from an operator. This practice could result in TC overlooking vital operational or maintenance related information which might otherwise have resulted

in an AD being issued. Therefore, the TSB recommends that:

> The Department of Transport evaluate its review process concerning Letters-to-Operators to ensure the continuing airworthiness and safe operation of Canadian-registered aircraft.
>
> (A91-20)

In addition, operator compliance requirements with respect to service bulletins are detailed in Notice To Aircraft Maintenance Engineers And Aircraft Owners (N-AME-AO) No. 26/83; however, compliance requirements with respect to Letters-to-Operators have not been promulgated. Therefore, the TSB recommends that:

> The Department of Transport clarify the operator compliance requirements with respect to Letters-to-Operators.
>
> (A91-21)

## 4.3 Safety Concern

### 4.3.1 Flight Crew Fatigue

The measures adopted by the operator (noted in section 4.1.1) address, in part, the circumstances which can cause a degradation of flight crew performance caused by fatigue. Nonetheless, many cargo operations, particularly those linking urban areas with "air express services", are flown by pilots who are subject to sleep dysrhythmia and the adverse effects of variable work shift patterns. The Board recognizes the need for the overnight air cargo industry; however, it is concerned that many operators utilize shift cycles and operating conditions which do not take adequate account of the resultant degradation in human performance.

The CASB had a long-standing concern with respect to the adverse effect of fatigue on aviation safety. The TSB is aware of these concerns and has been closely following the progress of the Minister's Advisory Committee on Flight Duty Time Limitations.

This report and the safety action therein have been adopted by the Chairman, J.W. Stants, and Board Members.

## APPENDIX B

## LIST OF LABORATORY REPORTS

The following laboratory reports were completed:

LP 127/88 - Structures Group;
LP 128/88 - Powerplants Group;
LP 129/88 - FDR/CVR Analysis;
LP 134/88 - Systems;
LP 138/88 - Performance Analysis; and
LP 144/88 - Aileron Rigging.

These reports are available upon request from the Transportation Safety Board of Canada.

## APPENDIX C

## GLOSSARY

| | |
|---|---|
| AAIB | Air Accidents Investigation Branch |
| AD | Airworthiness Directive |
| AFM | aircraft flight manual |
| agl | above ground level |
| AMA | Airworthiness Manual Advisory |
| AME | aircraft maintenance engineer |
| ANO | Air Navigation Order |
| asl | above sea level |
| BAe | British Aerospace |
| BCAR | British Civil Air Regulation |
| CAA | Civil Aviation Authority |
| Capt | captain |
| CASB | Canadian Aviation Safety Board |
| CVR | cockpit voice recorder |
| deg | degree(s) |
| DME | distance measuring equipment |
| DOT | Department of Transport |
| EDT | eastern daylight time |
| FAR | Federal Air Regulations |
| FDR | flight data recorder |
| fpm | feet per minute |
| FRPC | Flight Recorder Playback Centre |
| g | load factor |
| GPWS | Ground Proximity Warning System |
| hr | hour(s) |
| HSA | Hawker Siddeley Aviation Ltd. |
| ICAO | International Civil Aviation Organization |
| IFR | instrument flight rules |
| ILS | instrument landing system |
| KIAS | knots indicated airspeed |
| kts | knots |
| lat | latitude |
| lb | pound(s) |
| long | longitude |
| MHz | megahertz |
| min | minute(s) |
| MM | Maintenance Manual |
| N | north |
| N-AME-AO | Notice to Aircraft Maintenance Engineers and Aircraft Owners |
| nm | nautical mile(s) |
| NTO | Notice to Operators |
| OW | Ottawa |
| P/N | part number |

## GLOSSARY

| | |
|---|---|
| PPC | pilot proficiency check |
| psi | pounds per square inch |
| REM | Rapid Eye Movement |
| RT | reference time |
| SDA | Service Difficulty Advisory |
| TACAN | Tactical Air Navigation Equipment |
| TC | Transport Canada |
| TSB | Transportation Safety Board of Canada |
| U.S. | United States of America |
| UTC | Coordinated Universal Time |
| $V_A$ | manoeuvring airspeed |
| $V_C$ | design cruising airspeed |
| $V_{NE}$ | never-exceed (placard) airspeed |
| $V_{NO}$ | normal operating limit airspeed |
| VOR | very high frequency omni-directional range |
| VSI | vertical speed indicator |
| W | west |
| * | degree(s) |
| ' | minute(s) |
| " | second(s) |